APRENDE WP2-WP4 workshop
Strasbourg, France, 26-27 Fev. 2025

From experimental data to FY evaluation : JEFF4.0 and future program

G. Kessedjian[1], A. Regonesi[1], N. Teixeira-Rua[1], S. M. Cheikh[1], O. Serot[1], A. Chebboubi[1], D. Bernard[1]

[1] CEA, DES, IRESNE, DER, SPRC, LEPh, Cadarache center, F-13108 Saint Paul lez Durance, France

APRENDE Subtask 4.3.1 Fission yield evaluation

Context: a new methodology of FY Evaluation to define future experimental programs

Theoretically *Experimentally*

$$Y(A^*,Z,E^*,J^\pi) = Y(A^*,Z) \times P(E_K|A^*,Z) \times P(E^*,J^\pi|A^*,Z,EK) \leftrightarrow Y(A,Z,E_K,I\,) = Y(A) \times P(Z|A,E_K) \times P(E_k|A,Z) \times P(m|A,Z,E_K)$$

Pre-neutrons Mass, charge, excitation energy

Mass Charge Kinetic Energy Isomeric

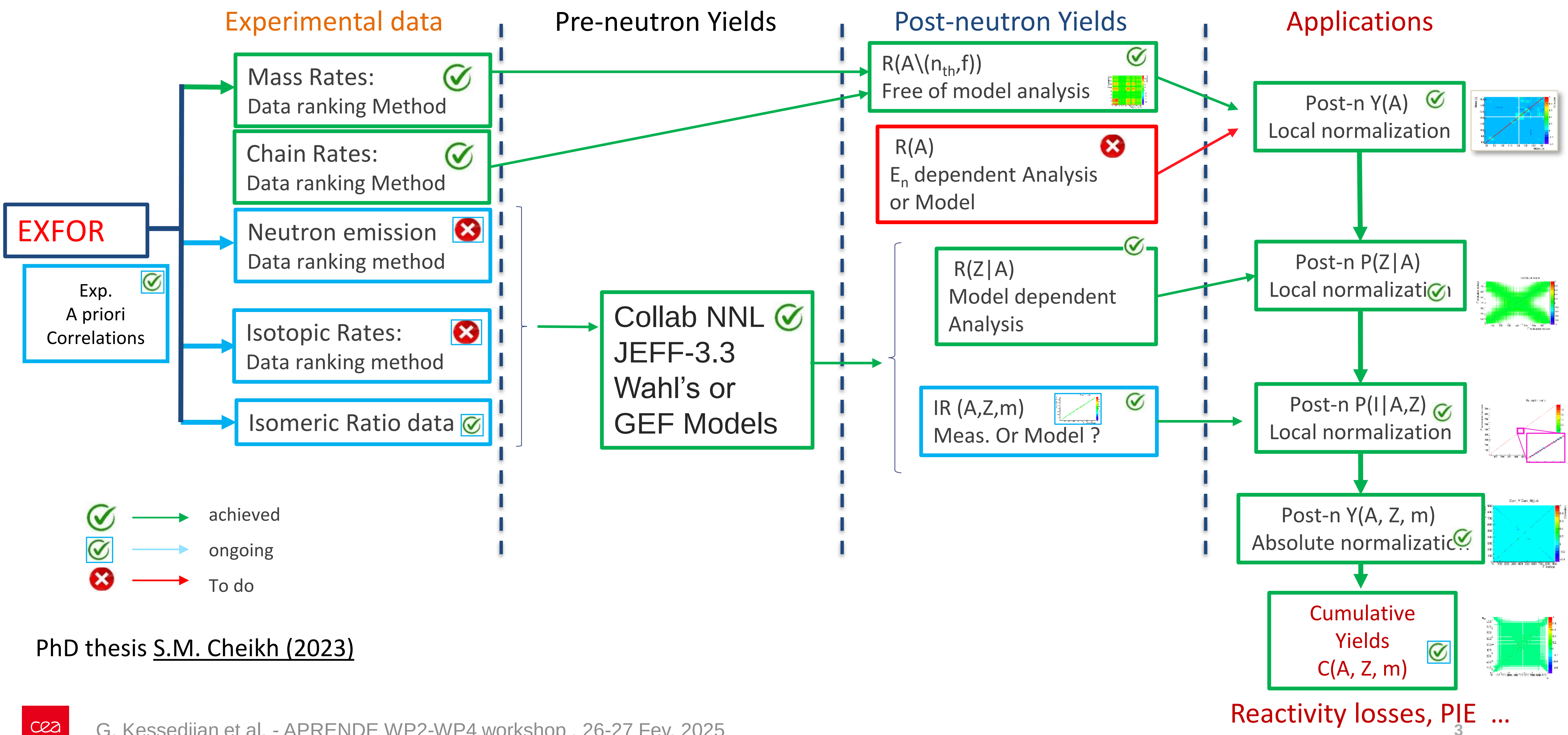
Applications : $\boldsymbol{Y(A,Z,m)}$ **independent fission yields** → **Decay data** → $\boldsymbol{C(A,Z,m)}$ **Cumulative fission yields**

In JEFF evaluation, independent and cumulative yields are two different evaluations due to the precise knowledge of chain yields (by radiochemical methods)

Full statistical description of fission observables : mean value, variance, covariance , PDF

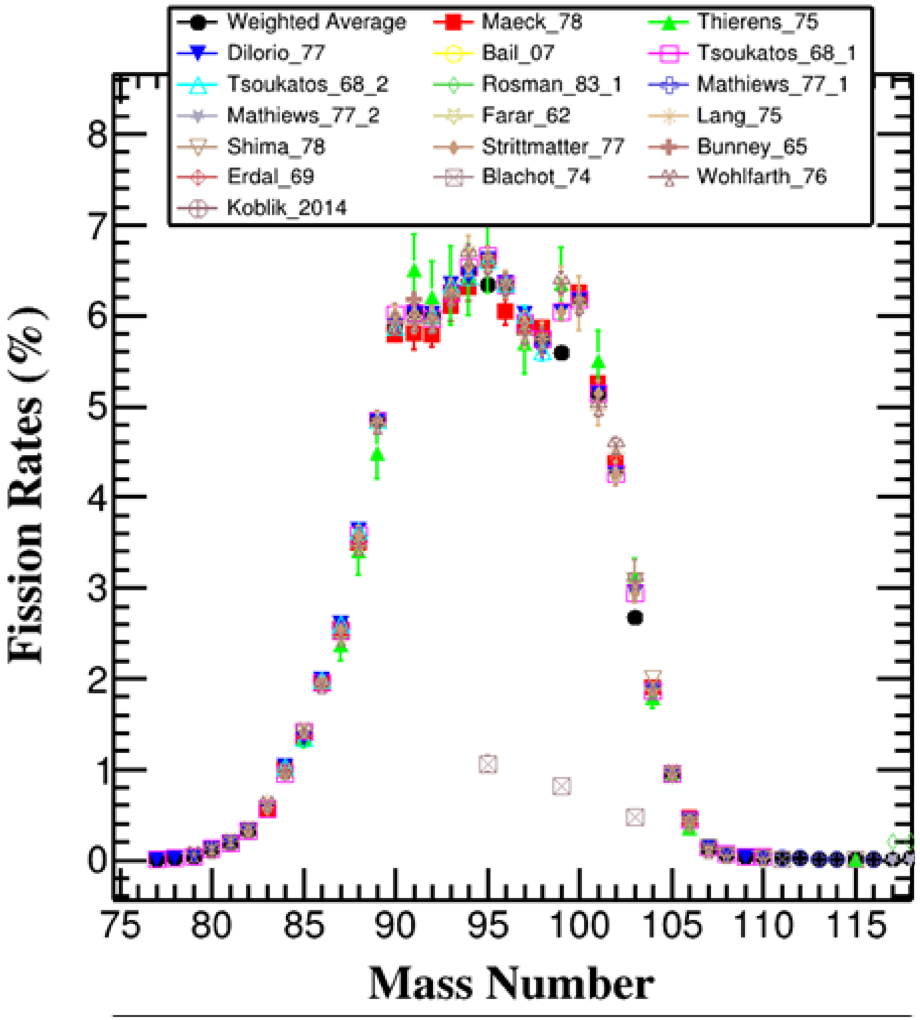
- Evaluations / measurements : no/ rare available covariance
- Mass = ∑ Isotope ⟶ Major constraint for covariance matrix
- Variance(Mass) = ∑ Var(Isotope) + ∑ Cov (Isotopes) → expected < ∑ Var(Isotope)
- In current evaluations Variance(Mass) > Var(major Isotope)

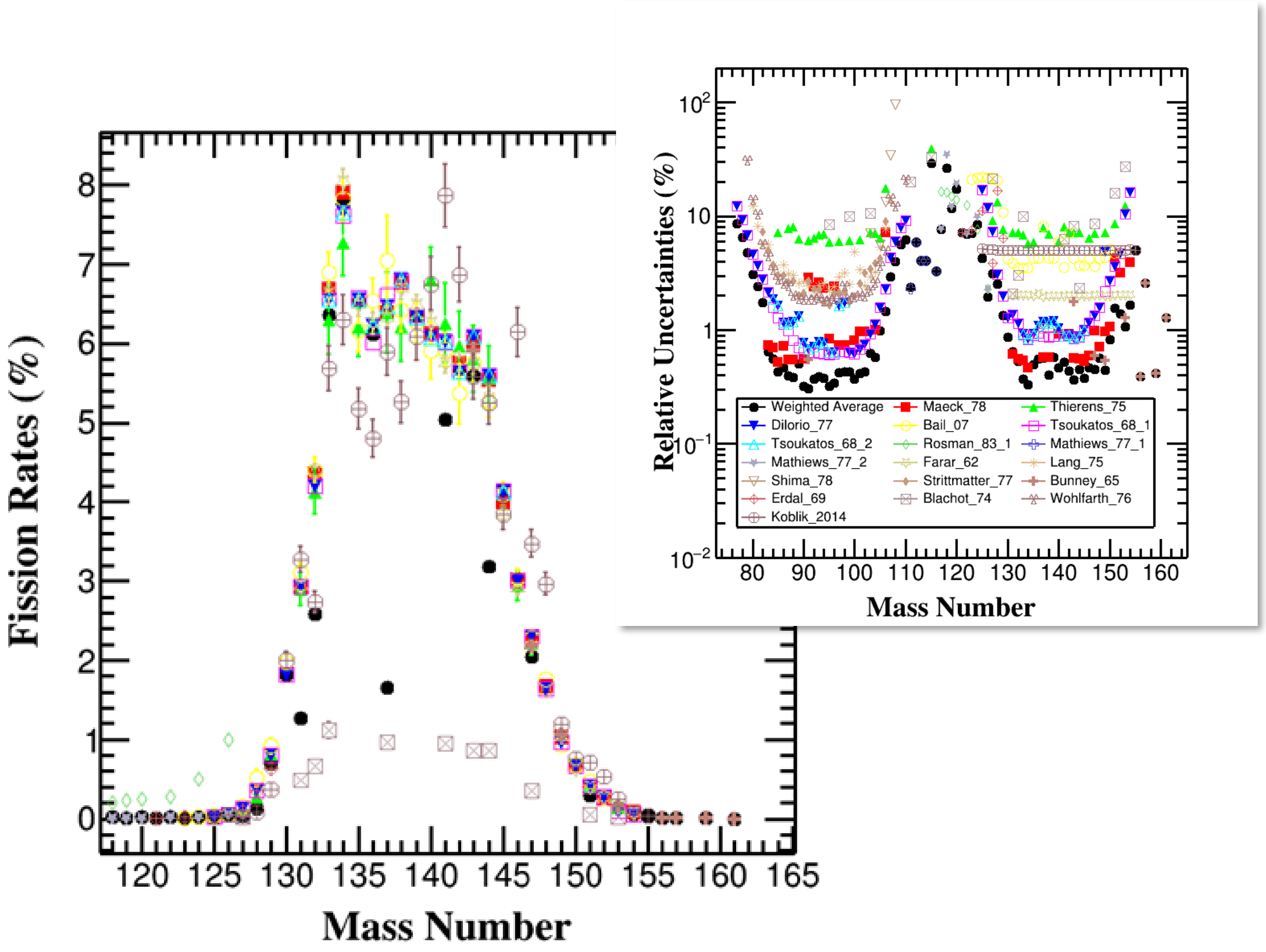
JEFF-4 Goal → New methodology : complete and consistent



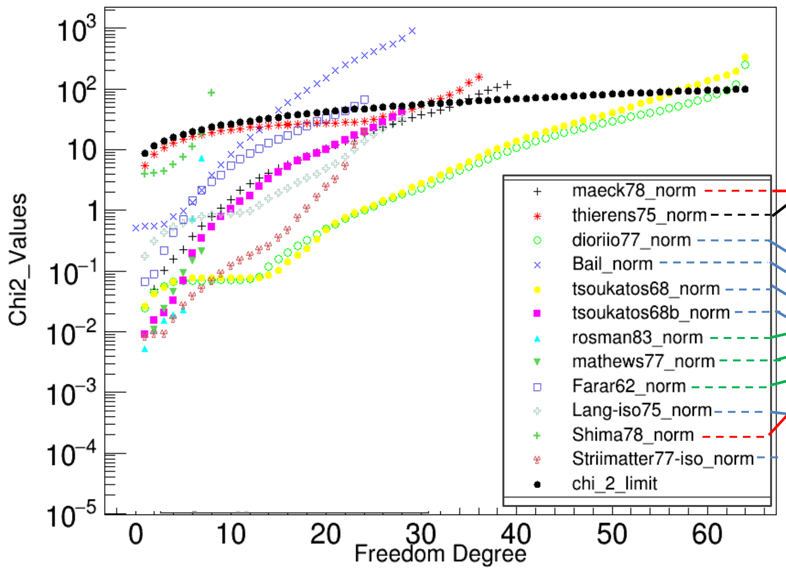
PhD thesis S.M. Cheikh (2023)

$^{235}U(n_{th},f)$: Raw datasets from EXFOR





Gaussian compatibility tests and sorting of data

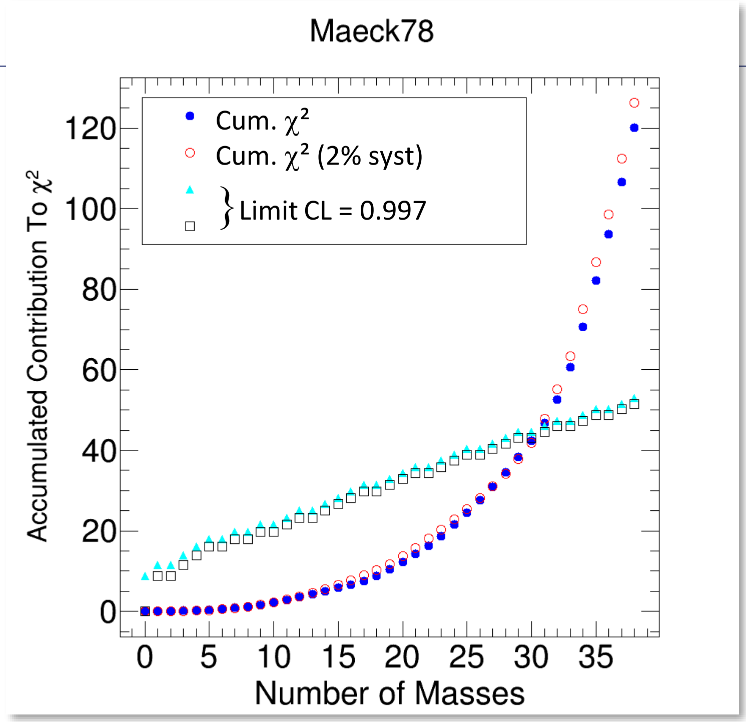


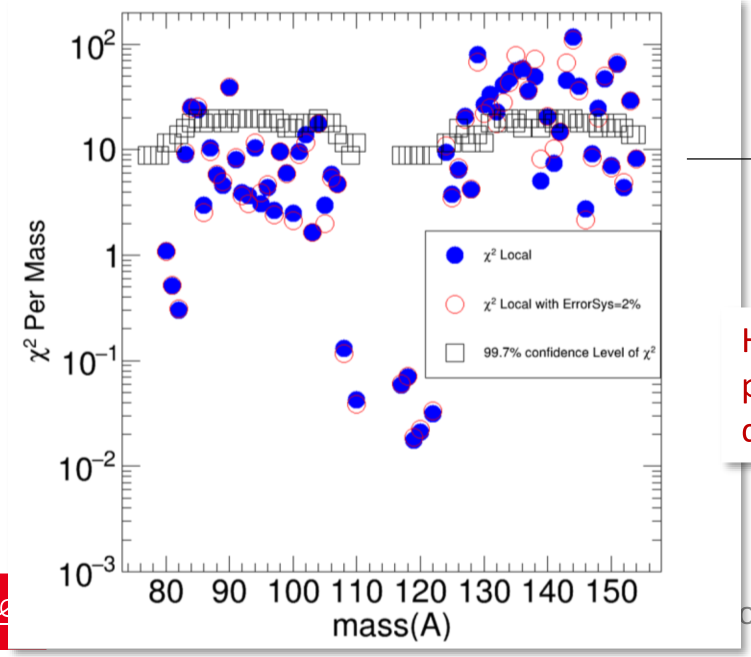
Cumulative yields
Gamma spectrometry

Cumulative yields
Radiochimical separation

Cumulative yields
Magnetic separation

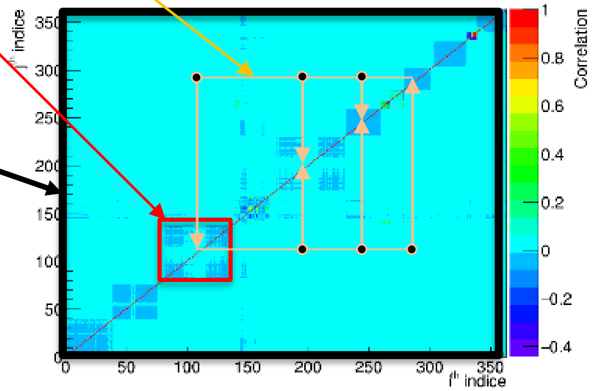
Magnetic spectrometers
HIAWATHA, LOHENGRIN





Heavy mass region presents a maximum of discrepancies

Mass measurement $\chi_g^2(A)$ test
Dataset $\chi_g^2(Dataset)$ test
Global χ_g^2 test



Example of re-interpretation of experimental data: reproducibility

Fickel1959 Chain yields

TABLE IX

Mass spectrometric and isotope dilution data for Cs^{133} produced in the thermal neutron fission of Pu^{239}

Sample	Isotope	Ratio before isotope dilution	No. of atoms of isotope added per g of Pu^{239}, $\times 10^{19}$	Ratio after isotope dilution	Calculated fission yield, atoms$\times 10^{18}$/g Pu^{239}
9	133	1.000	5.938	1.000	16.01
	137	0.9329±0.0089	—	0.1421±0.0008	—
8	133	1.000	7.853	1.000	18.35
	137	0.9322±0.0089	—	0.1765±0.0010	—
3	133	1.000	5.938	1.000	1.145
	137	0.9233±0.0135	—	0.02144±0.00028	—

TABLE X

Mass spectrometric and isotope dilution data for Sr^{90} produced in the thermal neutron fission of Pu^{239}

Sample	Isotope	Ratio before isotope dilution	No. of atoms of isotope added per g of Pu^{239}, $\times 10^{19}$	Ratio after isotope dilution	Calculated fission yield, atoms$\times 10^{18}$/g Pu^{239}
9	88	0.6595±0.0062	1.274	3.307±0.022	—
	90	1.000	—	1.000	4.846
8	88	0.6599±0.0062	1.122	2.593±0.011	—
	90	1.000	—	1.000	5.849
3	88	1.191±0.012	0.6678	1.975±0.035	—
	90	1.000	—	1.000	0.3656

TABLE XIII

Cumulative fission yields of the light fragments in the thermal neutron fission of Pu^{239} normalized to the 6.90% Cs^{133} yield

Isotopic mass	Sample 3		Sample 8		Sample 9		Average
	Atoms$\times 10^{18}$	% yield	Atoms$\times 10^{18}$	% yield	Atoms$\times 10^{18}$	% yield	% yield
72–82							0.59*
Kr^{83}							0.29
Kr^{84}							0.47
Rb^{85} (Kr^{85})			1.460	0.5456	1.262	0.5251	0.535
Kr^{86}							0.75
Rb^{87}			2.487	0.9291	0.2150	0.8942	0.912
Sr^{88}	0.2387	1.438	3.819	1.440	3.164	1.368	1.43
Sr^{89}	0.2868	1.728	4.589	1.726	3.802	1.639	1.71
Sr^{90}	0.3656	2.203	5.849	2.199	4.846	2.089	2.16
Zr^{91}							2.59
Zr^{92}							3.12
Zr^{93}							3.94
Zr^{94}							4.45
Mo^{95} (Zr^{95})			13.37	5.025	11.58	4.991	4.99
Zr^{96}							5.13
Mo^{97}			14.97	5.630	12.97	5.590	5.61
Mo^{98}			15.60	5.861	13.50	5.818	5.84
99							6.44*
Mo^{100}			1.882	7.072	1.629	7.020	7.05
Ru^{101}					13.60	5.860	5.86
Ru^{102}					13.78	5.939	5.94
Ru^{103}					13.06	5.626	5.63
Ru^{104}					13.64	5.877	5.88
105							5.50*
Ru^{106}					1.051	4.530	4.53
107							3.40*
108							2.44*
109							1.50†
110							0.76*
111							0.27†
112							0.10†
113							0.080*
114							0.060*
115							0.041*
116–118							0.122*
Cs^{133}	1.45	6.90	18.35	6.90	16.01	6.90	
Total % yield							100.12

*Interpolated values.
†Radiochemical yields.

Example of re-interpretation of experimental data: reproducibility

Fickel1959 Chain yields

A	Sample 1	Sample 2	Sample 3	Emirical Mean	Empirical Sandard Deviation	Student Standard deviation
83	0.29					
84	0.47					
85	0.5456	0.5251		0.53535	0.0145	4.9%
86	0.75					
87	0.9291	0.8942		0.91165	0.0247	4.9%
88	1.438	1.44	1.368	1.41533333	0.0580	5.4%
89	1.728	1.726	1.639	1.69766667	0.0719	5.6%
90	2.203	2.199	2.089	2.16366667	0.0915	5.6%
91	2.59					
92	3.12					
93	3.94					
94	4.45					
95	5.025	4.991		5.008	0.0240	0.9%
96	5.13					
97	5.63	5.59		5.61	0.0283	0.9%
98	5.861	5.818		5.8395	0.0304	0.9%
100	7.072	7.02		7.046	0.0368	0.9%
101	5.86					
102	5.94					
103	5.63					
104	5.88					
106	4.53					
109	1.5					
111	0.27					
112	0.1					
133	6.9					

Mean Student Unc.	3.34%
Min Student Unc.	0.9%

A	Sample 1	Sample 2	Emirical Mean	Empirical Sandard Deviation	Student Standard deviation
131	3.8	3.73	3.77	0.0495	2.4%
132	5.3	5.21	5.26	0.0636	2.2%
133	6.96	6.83	6.90	0.0919	2.4%
134	7.52	7.39	7.46	0.0919	2.2%
135	7.32	7.17	7.25	0.1061	2.7%
136	6.69	6.56	6.63	0.0919	2.5%
137	6.54	6.42	6.48	0.0849	2.4%
138	0	6.25	6.25		3.0%
140	5.5	5.66	5.58	0.1131	3.7%
142	4.9	5.03	4.97	0.0919	3.4%
143	4.5	4.61	4.56	0.0778	3.1%
144	3.78	3.89	3.84	0.0778	3.7%
145	3.08	3.16	3.12	0.0566	3.3%
146	2.53	2.6	2.57	0.0495	3.5%
147	2.02	1.96	1.99	0.0424	3.9%
148	1.69	1.73	1.71	0.0283	3.0%
149	1.32	1.28	1.30	0.0283	4.0%
150	1	1.03	1.02	0.0212	3.8%
151	0.814	0.79	0.80	0.0170	3.8%
152	0.625	0.606	0.62	0.0134	4.0%
154	0.297	0.289	0.29	0.0057	3.5%

Mean Student Unc.	3.2%
Min Student Unc.	2.2%

Example of re-interpretation of experimental data: experimental correlation matrix

Lowest possible estimation of the correlation matrix

Fickel1959_a

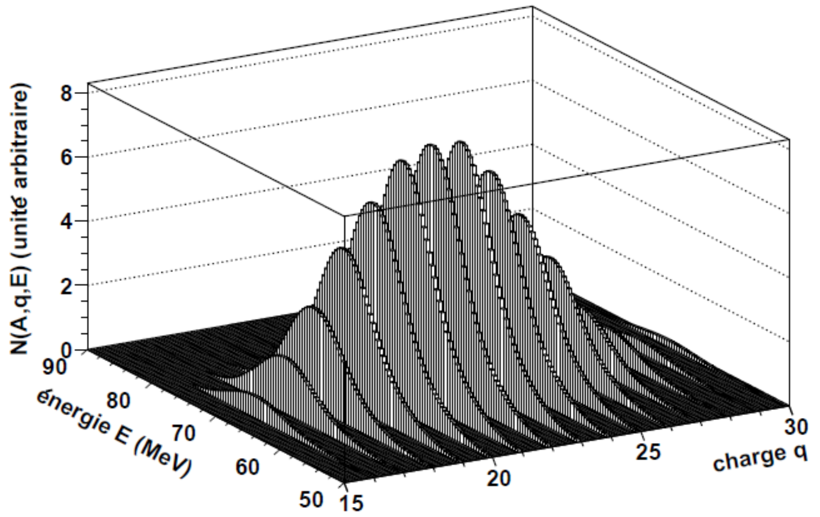
A	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	100	101	102	103	104	106	109	111	112	133
83	1.000	0.064	0.044	0.064	0.044	0.041	0.039	0.039	0.064	0.064	0.064	0.064	0.179	0.064	0.175	0.172	0.171	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.253
84	0.064	1.000	0.044	0.064	0.044	0.041	0.039	0.039	0.064	0.064	0.064	0.064	0.179	0.064	0.175	0.172	0.171	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.253
85	0.044	0.044	1.000	0.044	0.871	0.028	0.027	0.027	0.044	0.044	0.044	0.044	0.123	0.044	0.120	0.118	0.118	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.175
86	0.064	0.064	0.044	1.000	0.044	0.041	0.039	0.039	0.064	0.064	0.064	0.064	0.179	0.064	0.175	0.172	0.171	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.253
87	0.044	0.044	0.871	0.044	1.000	0.028	0.027	0.027	0.044	0.044	0.044	0.044	0.123	0.044	0.120	0.118	0.118	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.044	0.175
88	0.041	0.041	0.028	0.041	0.028	1.000	0.612	0.789	0.041	0.041	0.041	0.041	0.113	0.041	0.110	0.109	0.108	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.041	0.160
89	0.039	0.039	0.027	0.039	0.027	0.612	1.000	0.776	0.039	0.039	0.039	0.039	0.110	0.039	0.107	0.105	0.105	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.155
90	0.039	0.039	0.027	0.039	0.027	0.789	0.776	1.000	0.039	0.039	0.039	0.039	0.110	0.039	0.107	0.105	0.105	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.155
91	0.064	0.064	0.044	0.064	0.044	0.041	0.039	0.039	1.000	0.344	0.713	0.482	0.446	0.508	0.175	0.172	0.171	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.253
92	0.064	0.064	0.044	0.064	0.044	0.041	0.039	0.039	0.344	1.000	0.482	0.326	0.302	0.344	0.175	0.172	0.171	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.253
93	0.064	0.064	0.044	0.064	0.044	0.041	0.039	0.039	0.713	0.482	1.000	0.677	0.626	0.713	0.175	0.172	0.171	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.253
94	0.064	0.064	0.044	0.064	0.044	0.041	0.039	0.039	0.482	0.326	0.677	1.000	0.423	0.482	0.175	0.172	0.171	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.253
95	0.179	0.179	0.123	0.179	0.123	0.113	0.110	0.110	0.446	0.302	0.626	0.423	1.000	0.345	0.488	0.241	0.411	0.179	0.179	0.179	0.179	0.179	0.179	0.179	0.179	0.707
96	0.064	0.064	0.044	0.064	0.044	0.041	0.039	0.039	0.508	0.344	0.713	0.482	0.345	1.000	0.175	0.348	0.595	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.064	0.253
97	0.175	0.175	0.120	0.175	0.120	0.110	0.107	0.107	0.175	0.175	0.175	0.175	0.488	0.175	1.000	0.467	0.467	0.175	0.175	0.175	0.175	0.175	0.175	0.175	0.175	0.690
98	0.172	0.172	0.118	0.172	0.118	0.109	0.105	0.105	0.172	0.172	0.172	0.172	0.241	0.348	0.467	1.000	0.586	0.172	0.172	0.172	0.172	0.172	0.172	0.172	0.172	0.678
100	0.171	0.171	0.118	0.171	0.118	0.108	0.105	0.105	0.171	0.171	0.171	0.171	0.411	0.595	0.467	0.586	1.000	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.171	0.677
101	0.064	0.064	0.044	0.064	0.044	0.041	0.039	0.039	0.064	0.064	0.064	0.064	0.179	0.064	0.175	0.172	0.171	1.000	0.701	0.794	0.698	0.363	0.064	0.064	0.064	0.253
102	0.064	0.064	0.044	0.064	0.044	0.041	0.039	0.039	0.064	0.064	0.064	0.064	0.179	0.064	0.175	0.172	0.171	0.701	1.000	0.557	0.489	0.254	0.064	0.064	0.064	0.253
103	0.064	0.064	0.044	0.064	0.044	0.041	0.039	0.039	0.064	0.064	0.064	0.064	0.179	0.064	0.175	0.172	0.171	0.794	0.557	1.000	0.554	0.288	0.064	0.064	0.064	0.253
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.064	0.179	0.064	0.175	0.172	0.171	0.698	0.489	0.554	1.000	0.253	0.064	0.064	0.064	0.253
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.064	0.179	0.064	0.175	0.172	0.171	0.363	0.254	0.288	0.253	1.000	0.064	0.064	0.064	0.253
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.064	0.179	0.064	0.175	0.172	0.171	0.064	0.064	0.064	0.064	0.064	1.000	0.064	0.064	0.253
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.064	0.179	0.064	0.175	0.172	0.171	0.064	0.064	0.064	0.064	0.064	0.064	1.000	0.064	0.253
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.064	0.179	0.064	0.175	0.172	0.171	0.064	0.064	0.064	0.064	0.064	0.064	0.064	1.000	0.253
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	0.253	0.707	0.253	0.690	0.678	0.677	0.253	0.253	0.253	0.253	0.253	0.253	0.253	0.253	1.000

Colour scale: 1 0.9 0.8 0.7 0.6 0.5 0.4 0.3 0.2 0.1 0 -0.1 -0.2 -0.3 -0.4 -0.5 -0.6 -0.7 -0.8 -0.9 -1

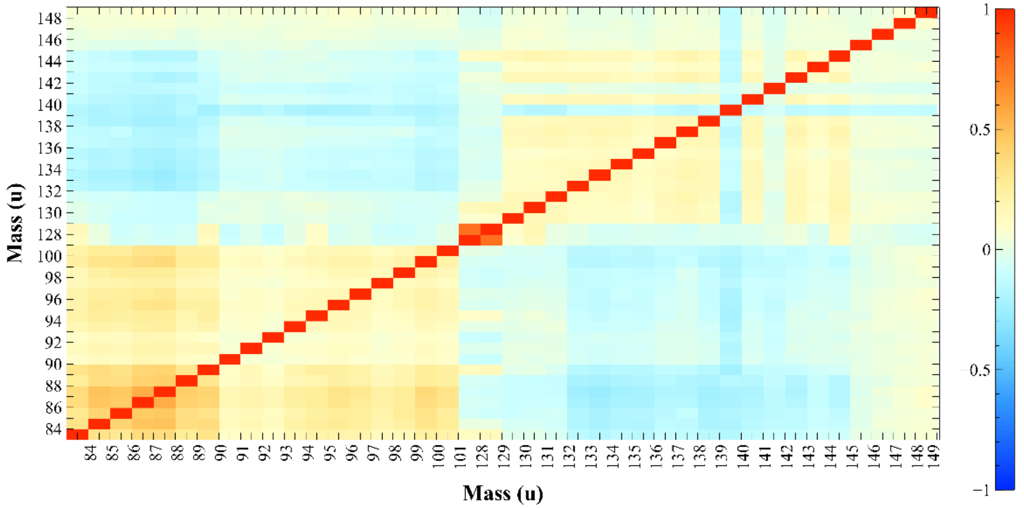
Fickel1959_b

0	131	132	133	134	135	136	137	138	140	142	143	144	145	146	147	148	149	150	151	152	154
131	1.000	0.105	0.772	0.131	0.113	0.118	0.124	0.101	0.084	0.091	0.098	0.083	0.093	0.087	0.080	0.101	0.078	0.081	0.080	0.078	0.087
132	0.105	1.000	0.081	0.141	0.121	0.127	0.134	0.109	0.090	0.098	0.105	0.090	0.100	0.094	0.086	0.108	0.084	0.087	0.086	0.084	0.094
133	0.772	0.081	1.000	0.130	0.111	0.117	0.123	0.100	0.082	0.090	0.097	0.082	0.092	0.086	0.079	0.100	0.077	0.080	0.079	0.077	0.086
134	0.131	0.141	0.130	1.000	0.119	0.493	0.132	0.802	0.088	0.096	0.104	0.088	0.098	0.092	0.084	0.107	0.083	0.086	0.085	0.082	0.092
135	0.113	0.121	0.111	0.119	1.000	0.108	0.113	0.092	0.076	0.083	0.089	0.076	0.084	0.080	0.072	0.092	0.071	0.074	0.073	0.071	0.079
136	0.118	0.127	0.117	0.493	0.108	1.000	0.119	0.615	0.080	0.087	0.093	0.080	0.088	0.083	0.076	0.096	0.074	0.077	0.076	0.074	0.083
137	0.124	0.134	0.123	0.132	0.113	0.119	1.000	0.102	0.084	0.091	0.098	0.084	0.093	0.088	0.080	0.101	0.078	0.081	0.080	0.078	0.088
138	0.101	0.109	0.100	0.802	0.092	0.615	0.102	1.000	0.068	0.074	0.080	0.068	0.076	0.071	0.065	0.082	0.064	0.066	0.065	0.064	0.071
140	0.084	0.090	0.082	0.088	0.076	0.080	0.084	0.068	1.000	0.802	0.669	0.056	0.062	0.059	0.054	0.068	0.053	0.055	0.054	0.052	0.059
142	0.091	0.098	0.090	0.096	0.083	0.087	0.091	0.074	0.802	1.000	0.835	0.061	0.068	0.064	0.058	0.074	0.057	0.059	0.059	0.057	0.064
143	0.098	0.105	0.097	0.104	0.089	0.093	0.098	0.080	0.669	0.835	1.000	0.782	0.787	0.724	0.063	0.682	0.062	0.743	0.063	0.062	0.069
144	0.083	0.090	0.082	0.088	0.076	0.080	0.084	0.068	0.056	0.061	0.782	1.000	0.616	0.566	0.054	0.533	0.053	0.581	0.054	0.052	0.059
145	0.093	0.100	0.092	0.098	0.084	0.088	0.093	0.076	0.062	0.068	0.787	0.616	1.000	0.570	0.060	0.537	0.058	0.585	0.060	0.058	0.065
146	0.087	0.094	0.086	0.092	0.080	0.083	0.088	0.071	0.059	0.064	0.724	0.566	0.570	1.000	0.056	0.494	0.055	0.538	0.057	0.055	0.062
147	0.080	0.086	0.079	0.084	0.072	0.076	0.080	0.065	0.054	0.058	0.063	0.054	0.060	0.056	1.000	0.065	0.520	0.052	0.367	0.410	0.316
148	0.101	0.108	0.100	0.107	0.092	0.096	0.101	0.082	0.068	0.074	0.682	0.533	0.537	0.494	0.065	1.000	0.064	0.506	0.065	0.063	0.071
149	0.078	0.084	0.077	0.083	0.071	0.074	0.078	0.064	0.053	0.057	0.062	0.053	0.058	0.055	0.520	0.064	1.000	0.051	0.660	0.737	0.567
150	0.081	0.087	0.080	0.086	0.074	0.077	0.081	0.066	0.055	0.059	0.743	0.581	0.585	0.538	0.052	0.506	0.051	1.000	0.052	0.051	0.057
151	0.080	0.086	0.079	0.085	0.073	0.076	0.080	0.065	0.054	0.059	0.063	0.054	0.060	0.057	0.367	0.065	0.660	0.052	1.000	0.521	0.401
152	0.078	0.084	0.077	0.082	0.071	0.074	0.078	0.064	0.052	0.057	0.062	0.052	0.058	0.055	0.410	0.063	0.737	0.051	0.521	1.000	0.448
154	0.087	0.094	0.086	0.092	0.079	0.083	0.088	0.071	0.059	0.064	0.069	0.059	0.065	0.062	0.316	0.071	0.567	0.057	0.401	0.448	1.000

Uncertainty estimation form Lohengrin of historical method



$^{235}U(n_{th},f)$ Y(A) (on going)



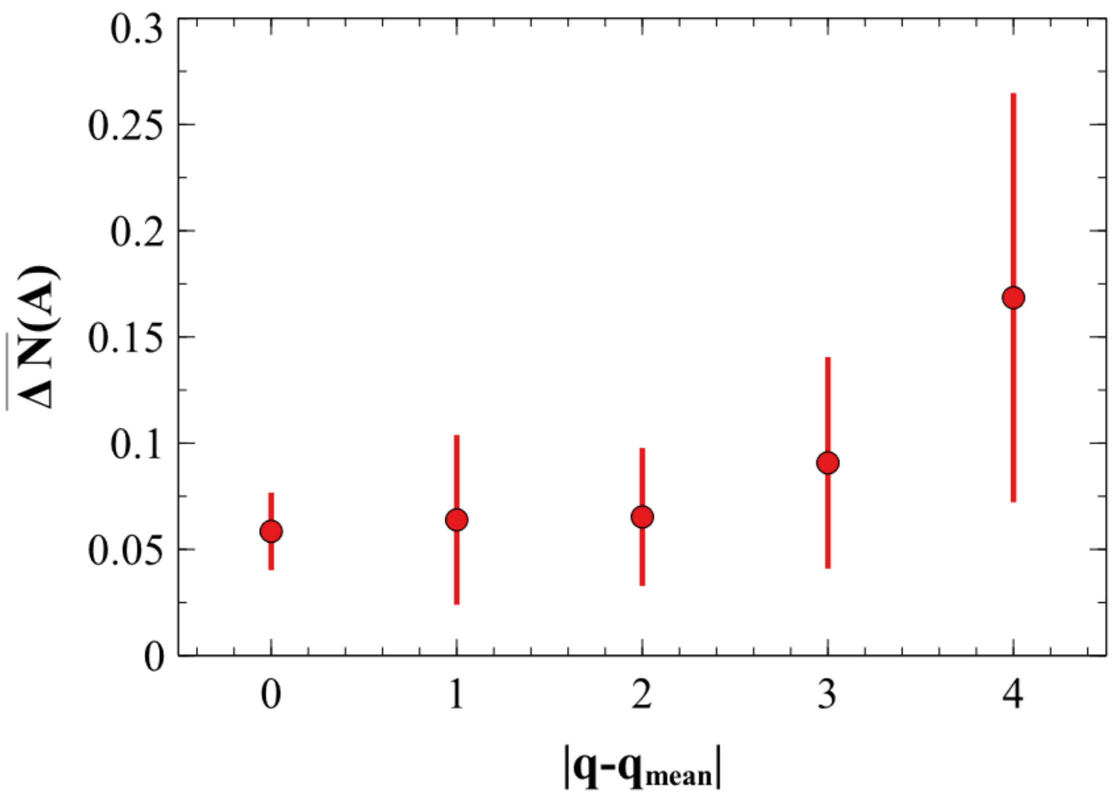


Fig. 10 Impact of the correlation (E_k, q) on the estimation of the relative mass yields. The bias rises from 5 to 17% when the scan is performed at a charge state q that differs more from q_{mean} is observed. See text for details

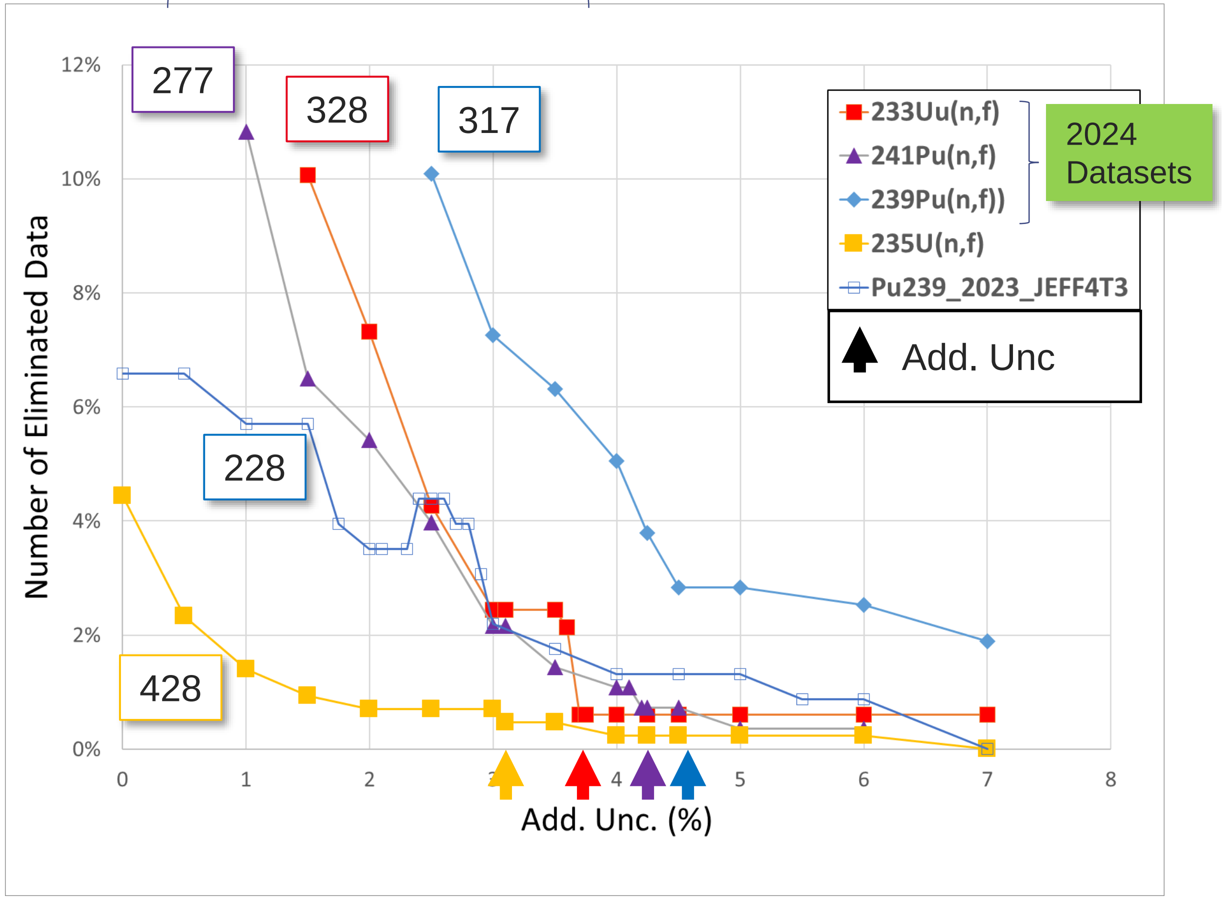
A. Chebboubi Eur. Phys. J. A (2021) 57: 335

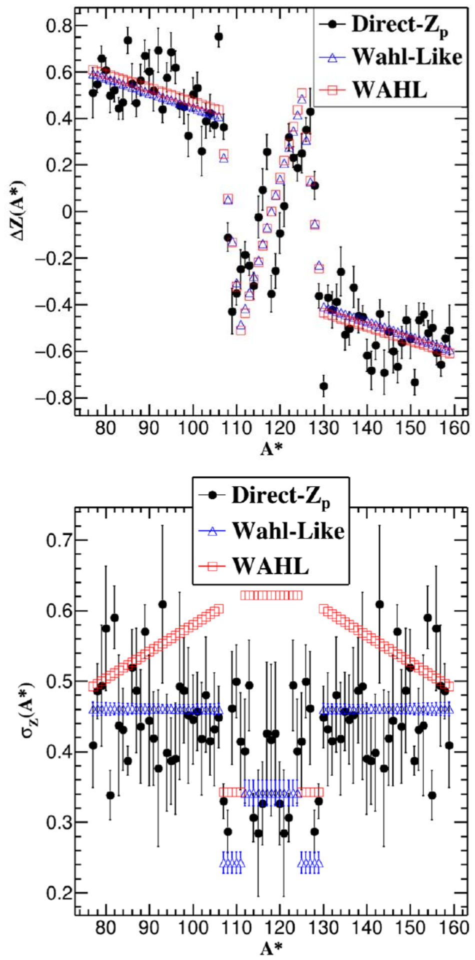
Test and sorting of available experimental data for the 4 main fissile nuclei

Integrating several cumulative yields ≡ chain yields according to P(Z|A,JEFF3.3) sorting

sorting depends on mean nuclear charge

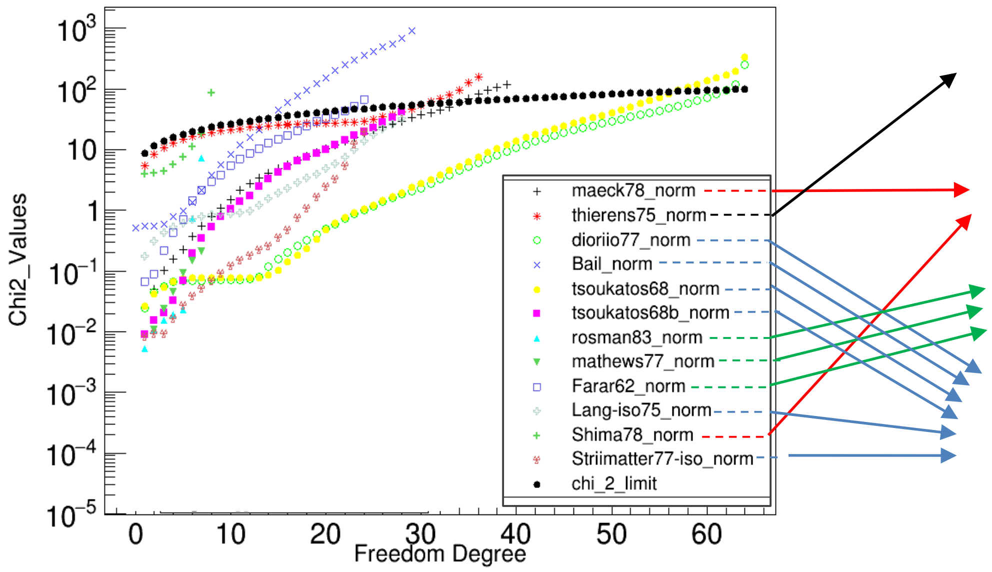
Only mass yields and chain yields used in these analyses





- S.-M. Cheikh, PhD thesis, UGA, 18 Oct. 2023
- S.-M. Cheikh, G. Kessedjian et al., Covariance Workshop 2022, Tokyo, Japan, EPJ Web of Conferences 281, 00023 (2023)

Gaussian compatibility tests and sorting of data

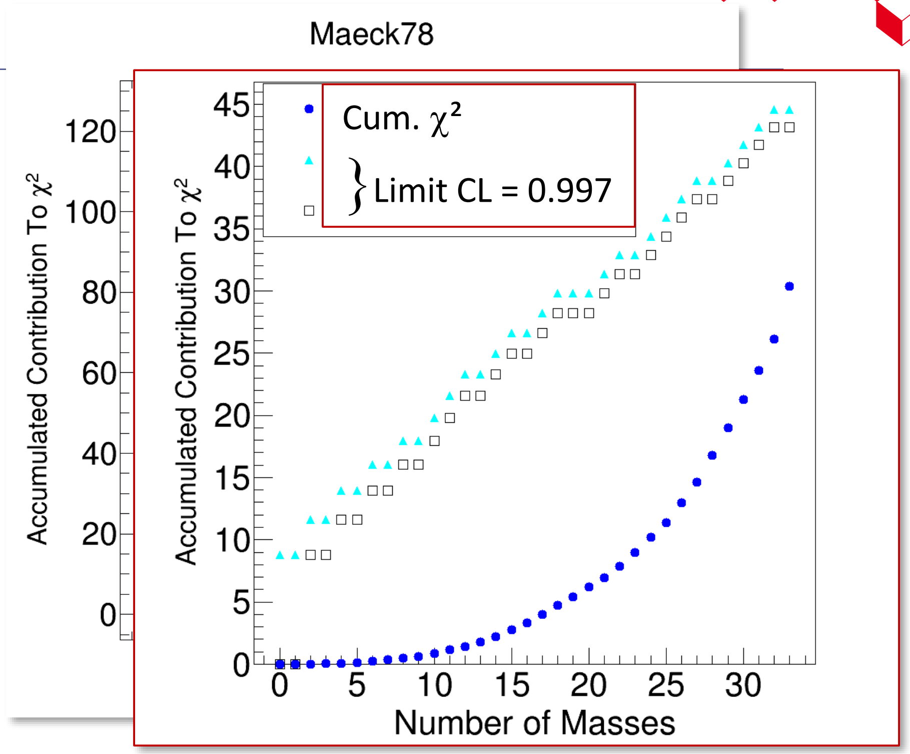


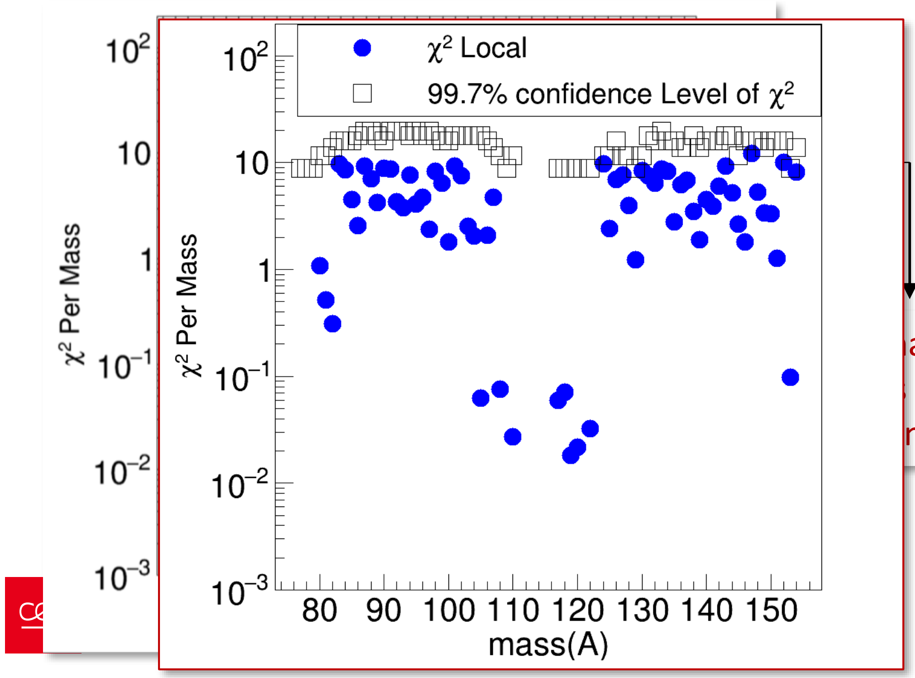
Cumulative yields
Gamma spectrometry

Cumulative yields
Radiochimical separation

Cumulative yields
Magnetic separation

Magnetic spectrometers
HIAWATHA, LOHENGRIN



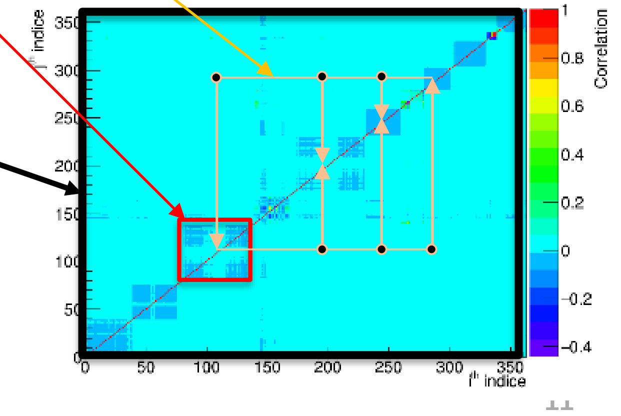


ass region
a maximum of
ncies

Mass measurement $\chi_g^2(A)$ test

Dataset $\chi_g^2(Dataset)$ test

Global χ_g^2 test



JEFF-4 Goal → New methodology : complete and consistent

S.-M. Cheikh, G. Kessedjian et al., Eur. Phys. J. A, 60 11 (2024) 222

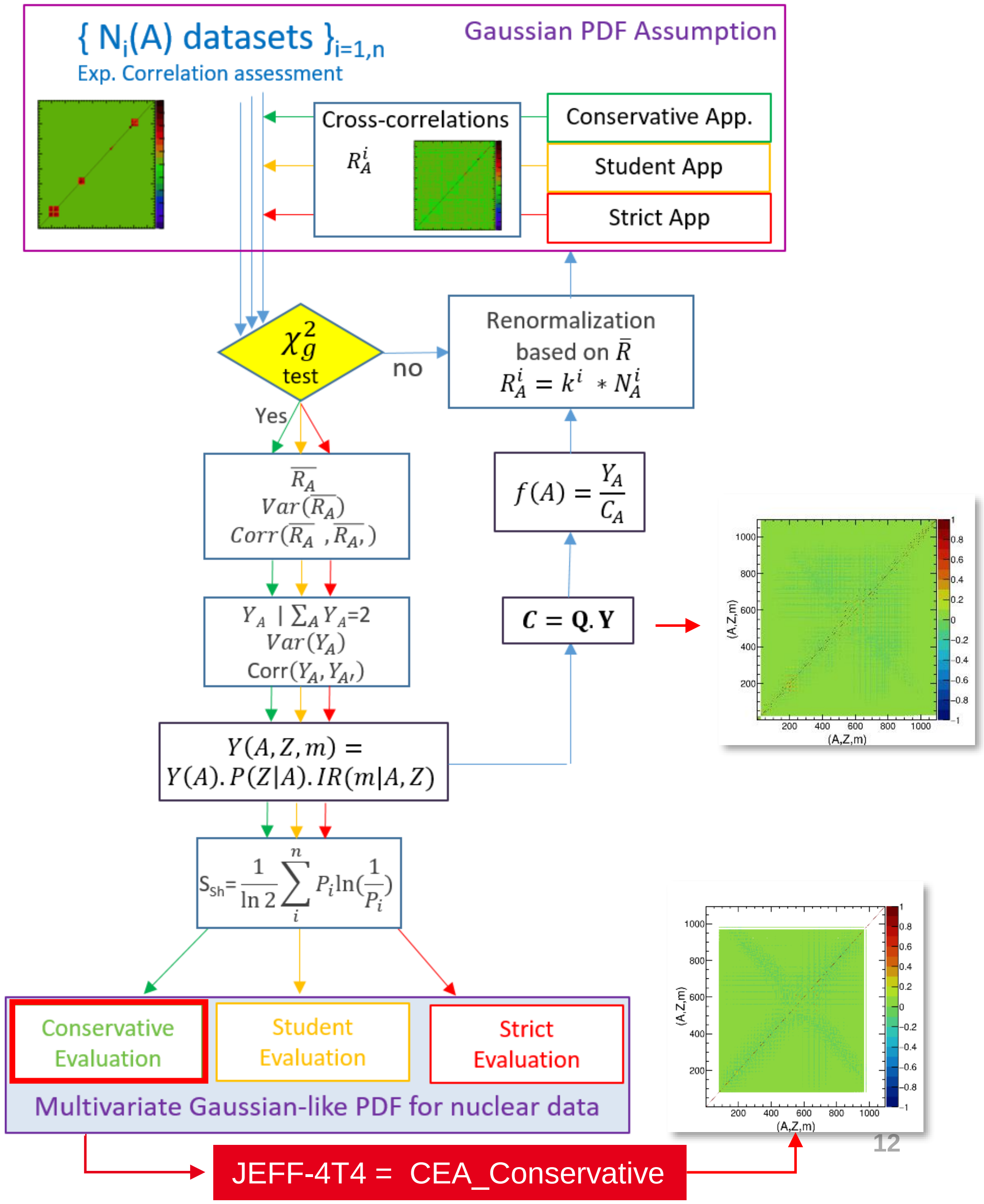
- ## Previous FY evaluations :

- Independent and Cumulative FY evaluations are two different evaluations : only mean values follow conservation laws
- Driven by the cumulative data
- Uncertainties of Ind. FY are overestimated due to the lack of correlation matrix as by-product of the analysis
- Covariance/correlation matrix of Ind FY is extrapolated assuming the C. Devillers methodology : Assumption Corr (C, C') = I

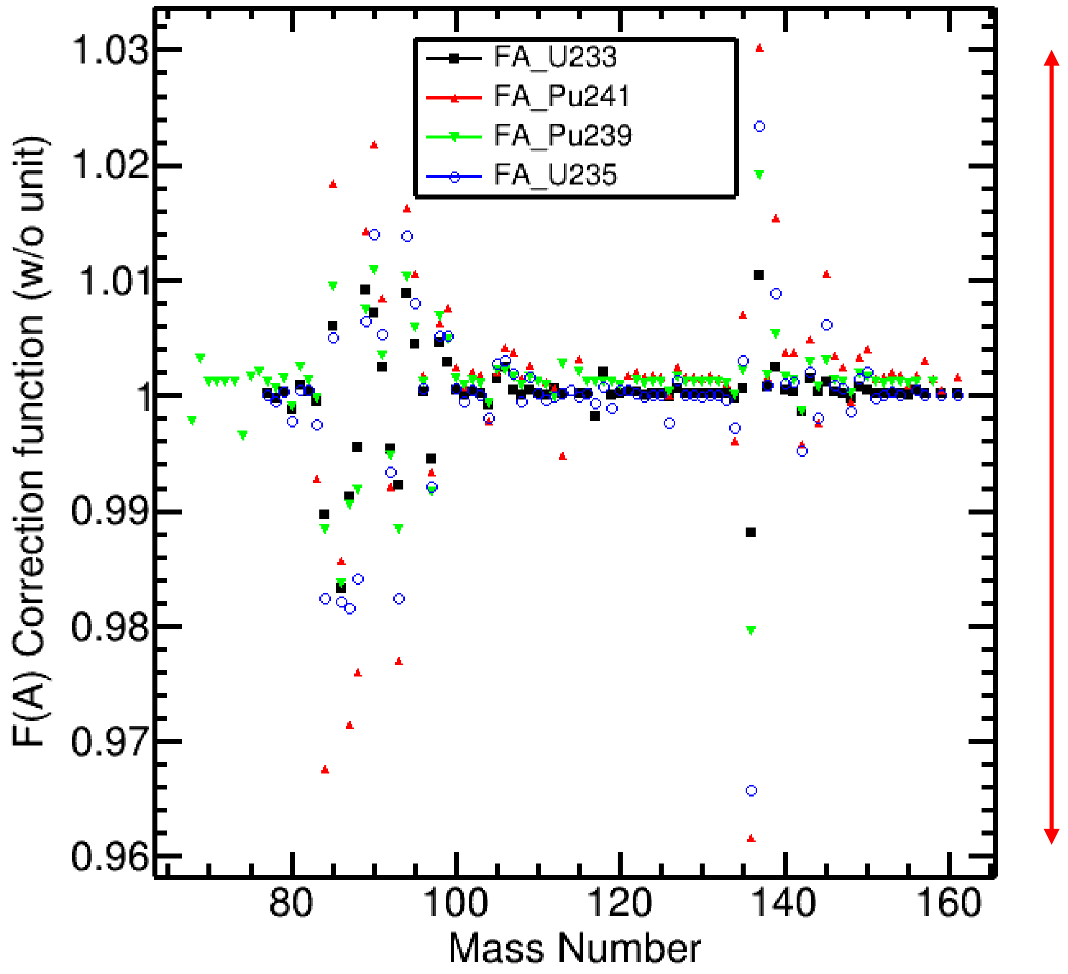
- ## JEFF-4 Evaluation

- Independent and Cumulative FY come from a unique evaluation
- Take into account the experimental correlation matrix available or deduced from literature
- Complete description of the fission yield observables
- Consistent according to the conservation laws for :

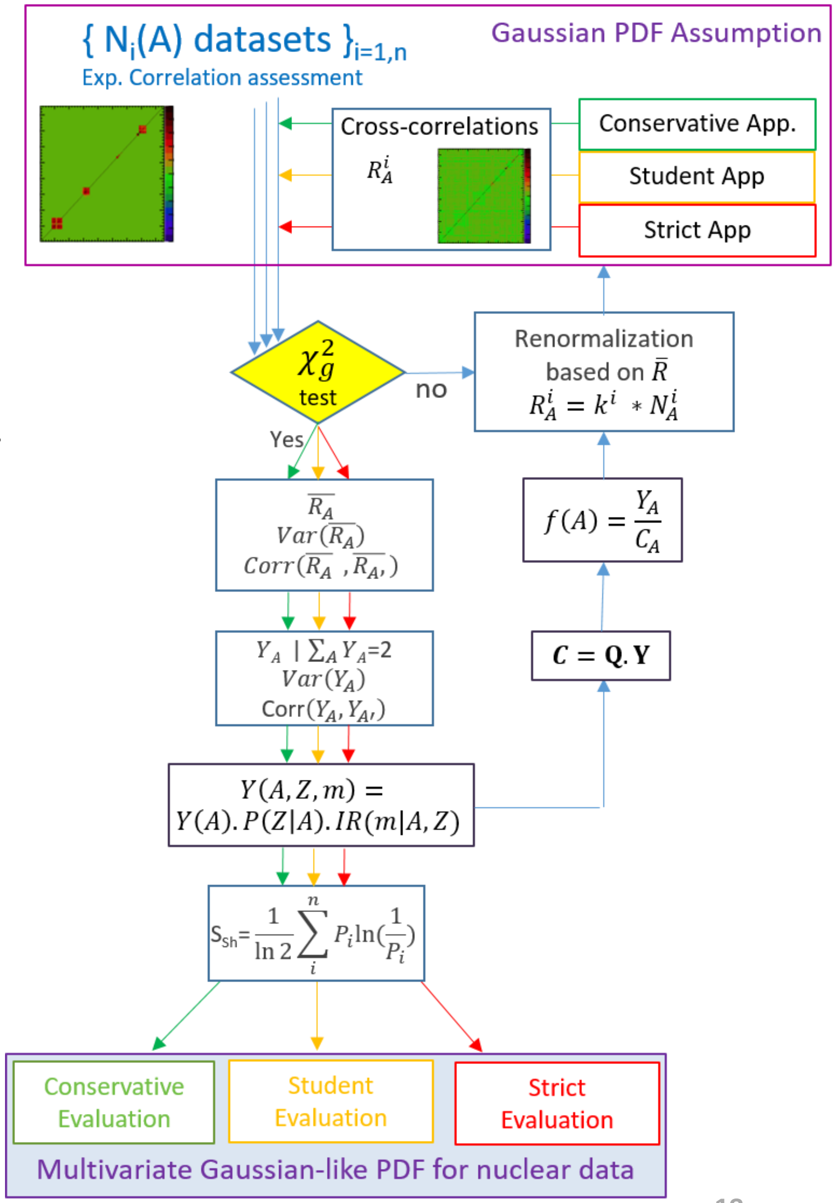
  mean values, uncertainties and correlation matrices



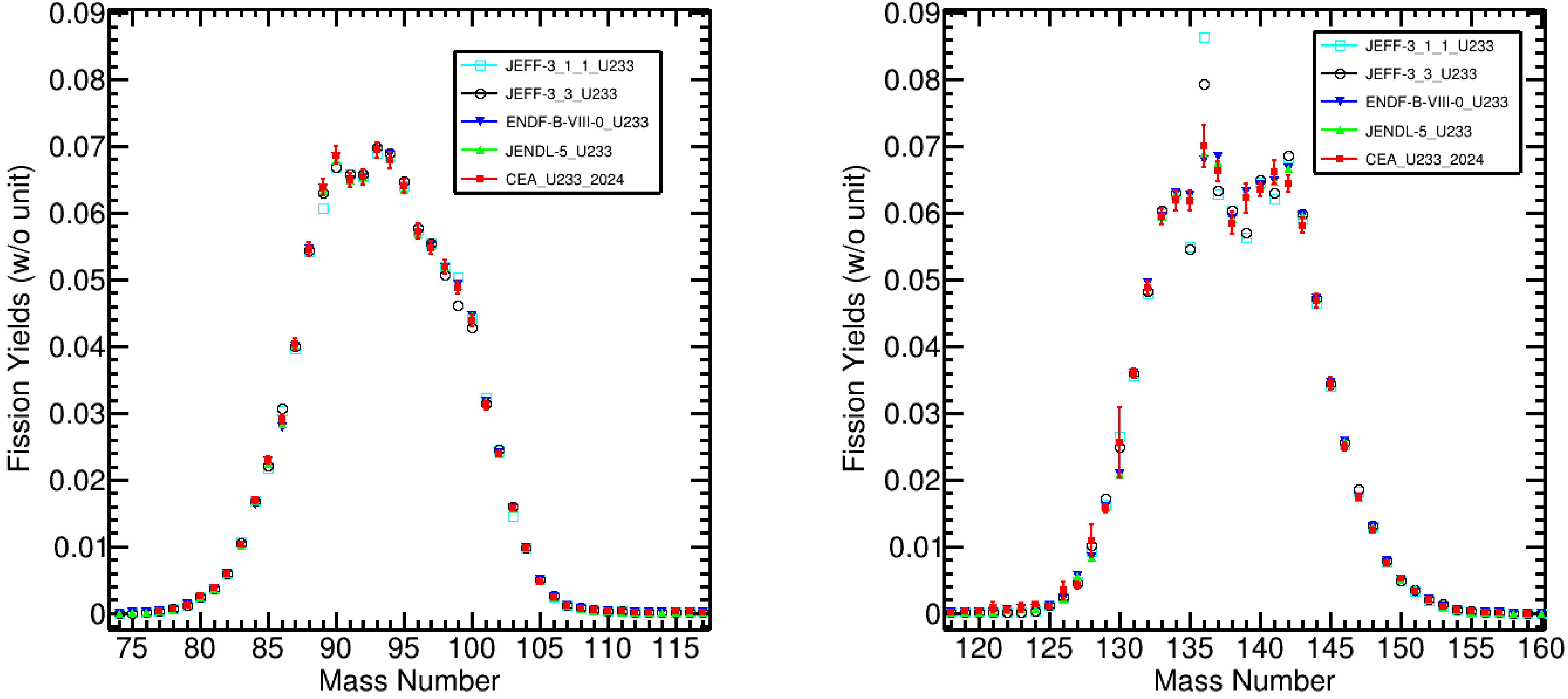
Test and sorting of available experimental data for the 4 main fissile nuclei



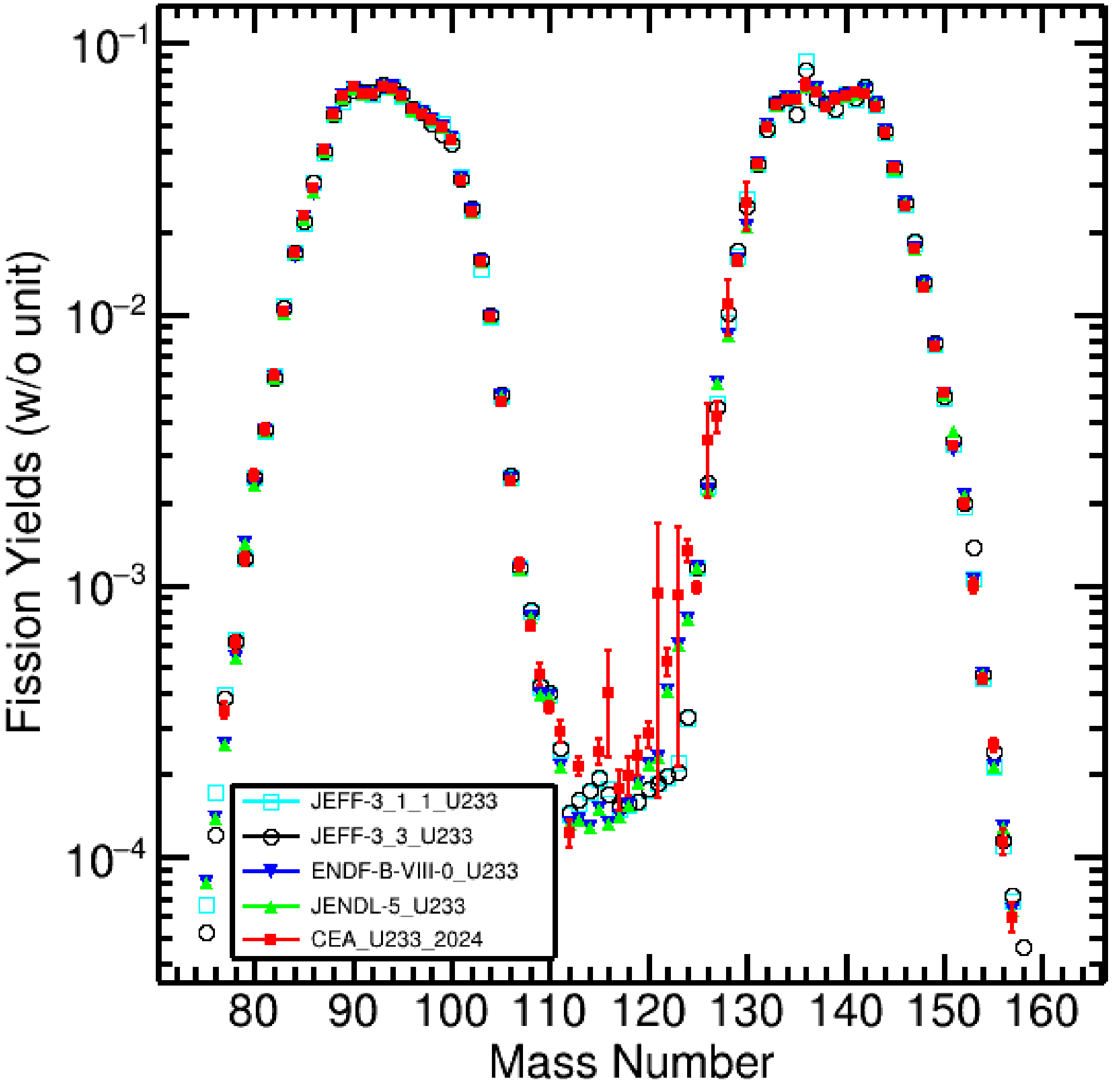
Up to 7% effect of JEFF-3.3 Decay Data in the combination of mass yield and chain yield datasets

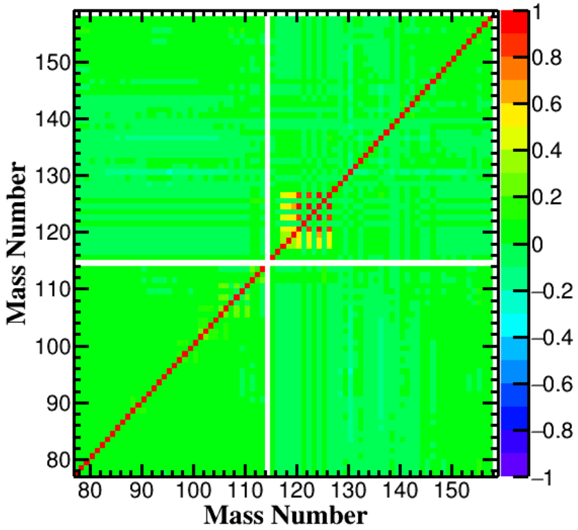


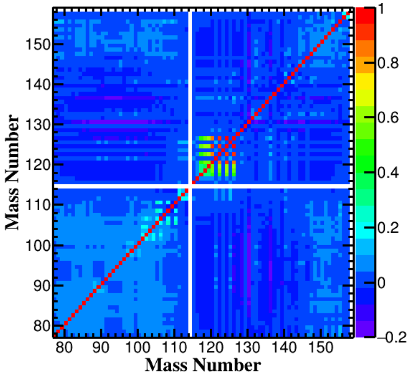
$^{233}U(n_{th},f)$: Mass yields

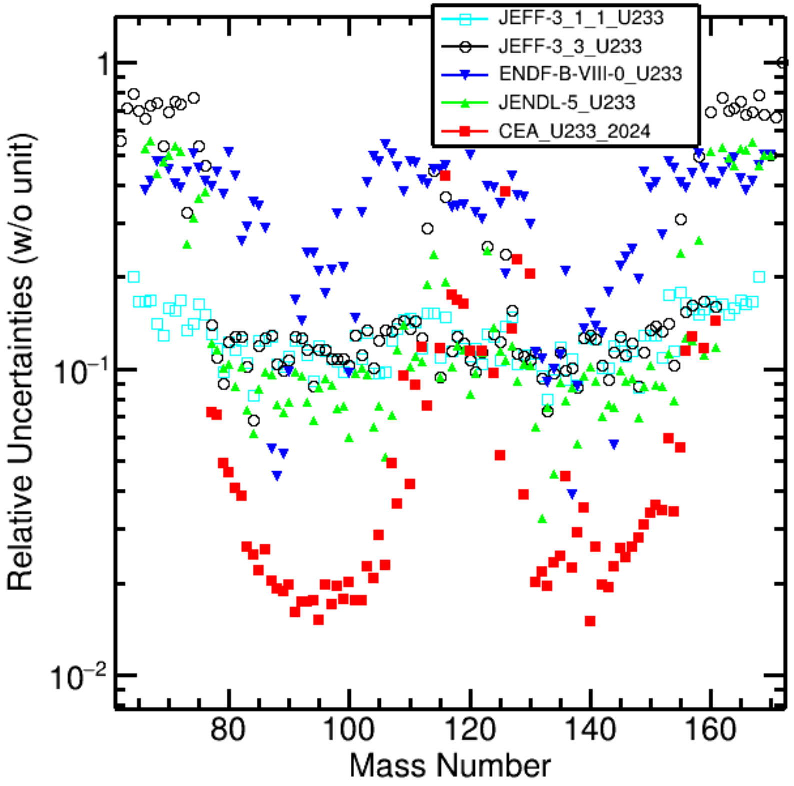


$^{233}U(n_{th},f)$: Mass yields

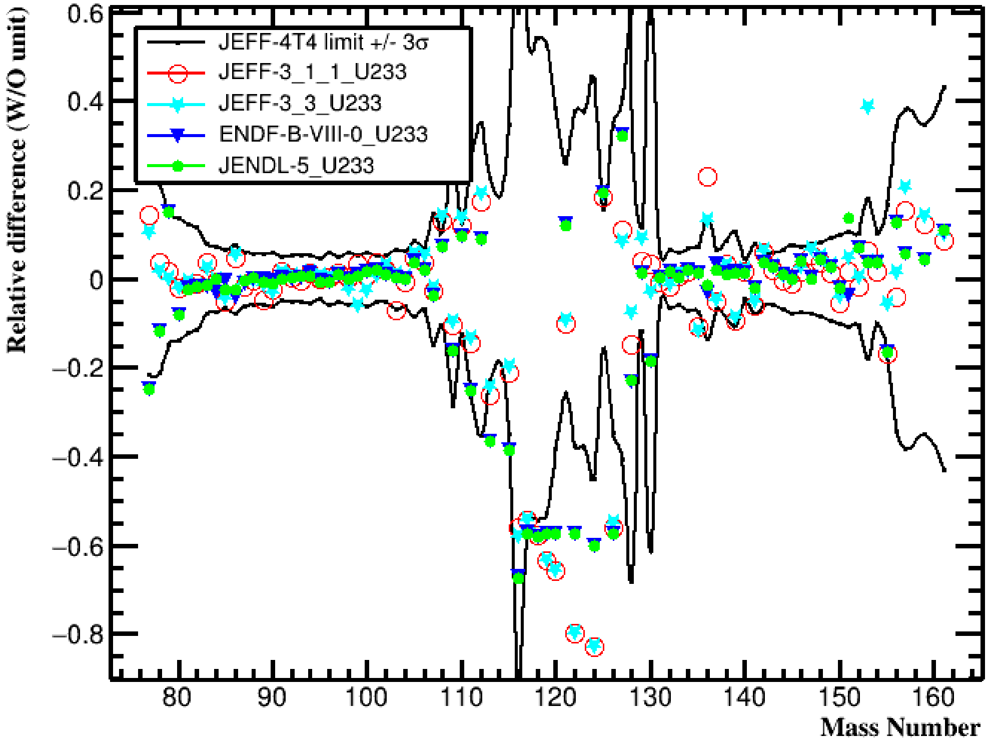


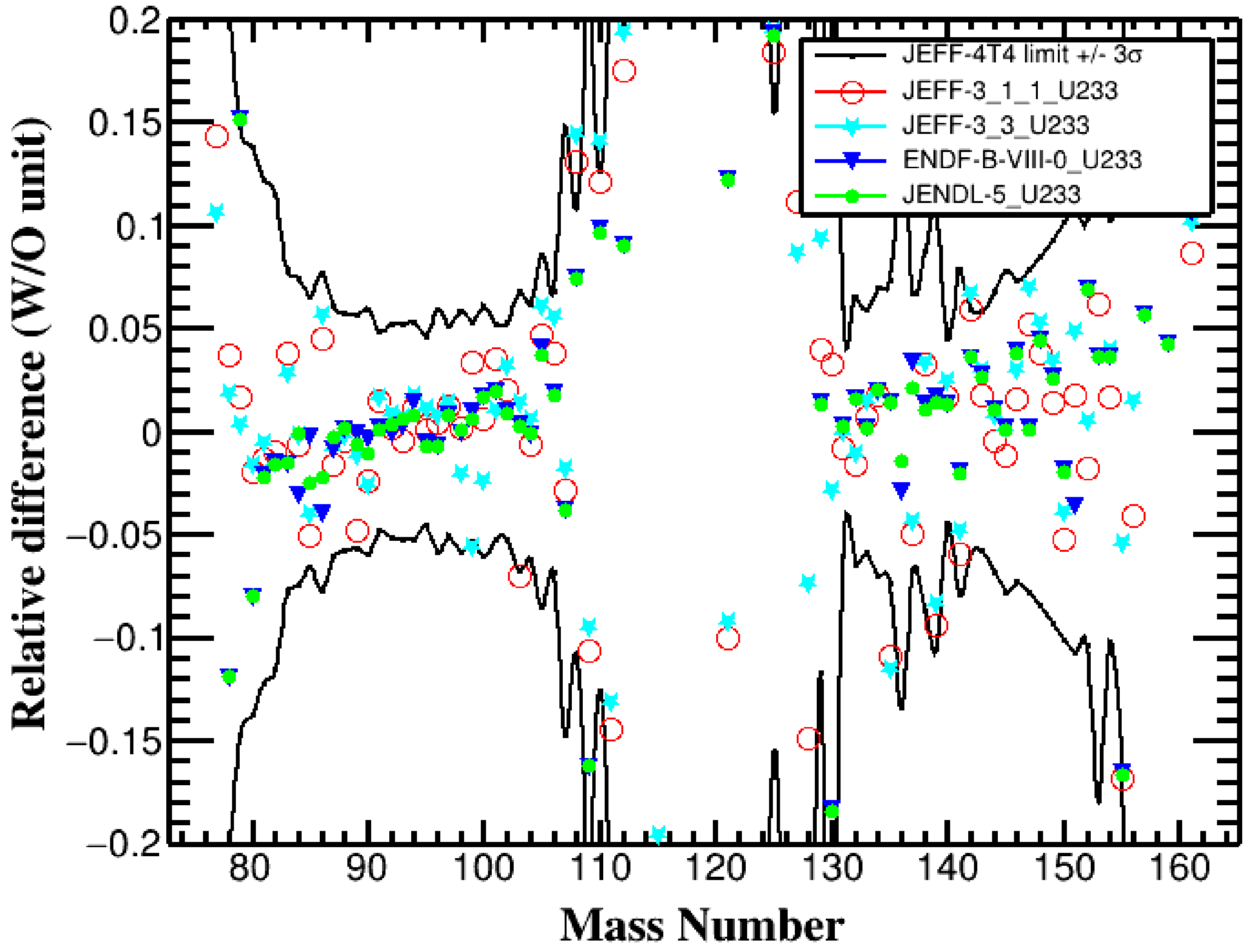




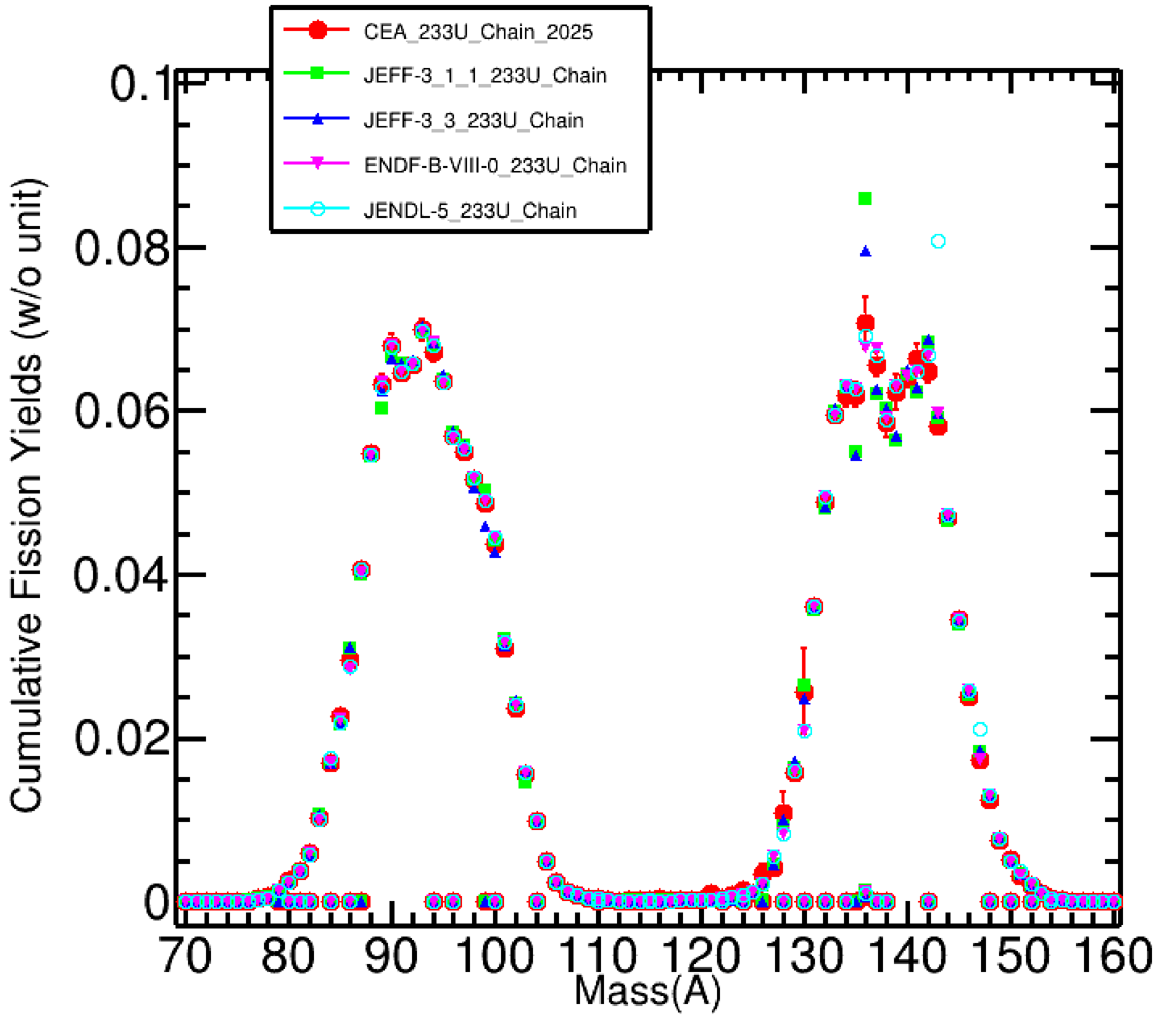


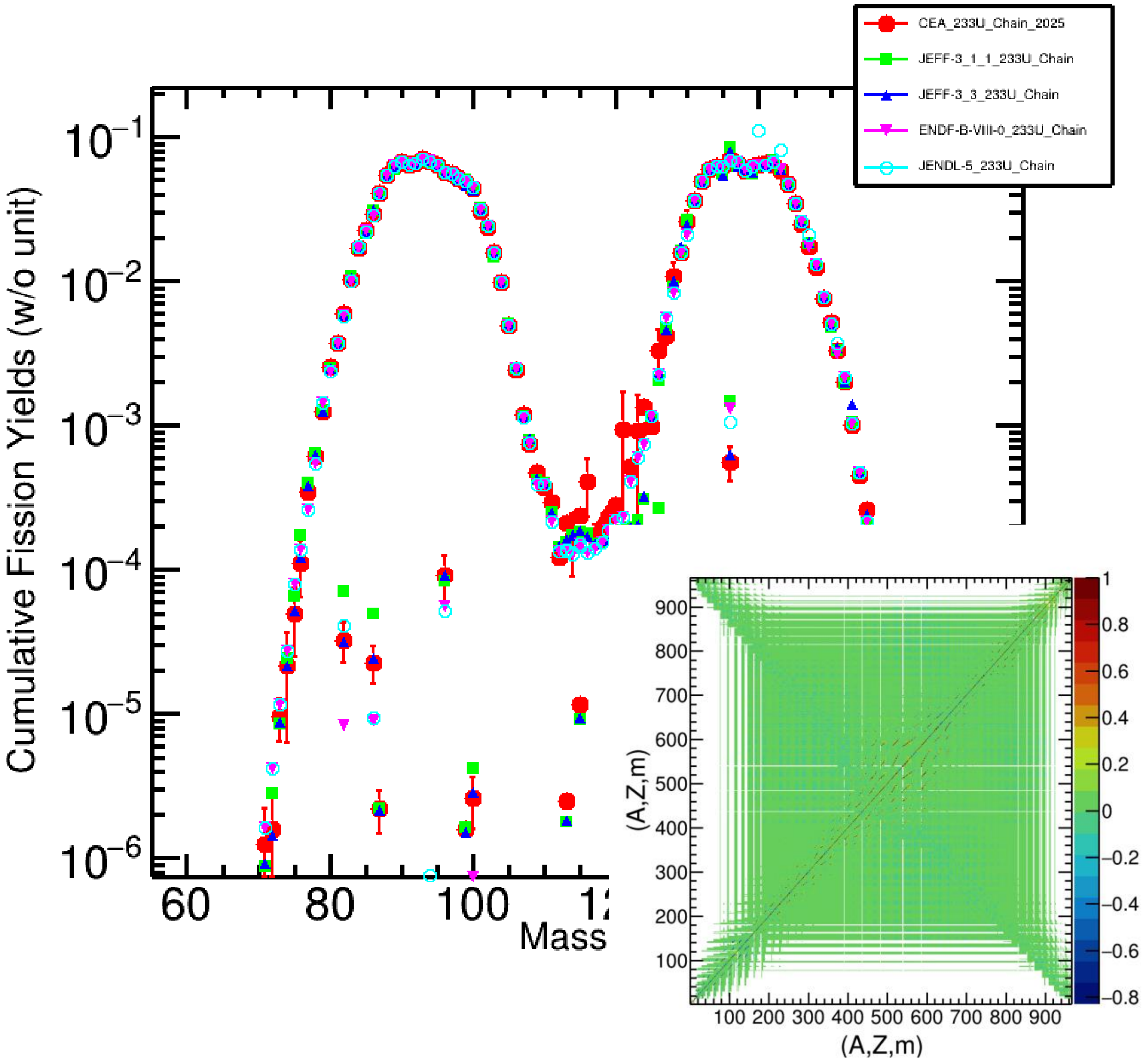
$^{233}U(n_{th},f)$: Exclusion plot



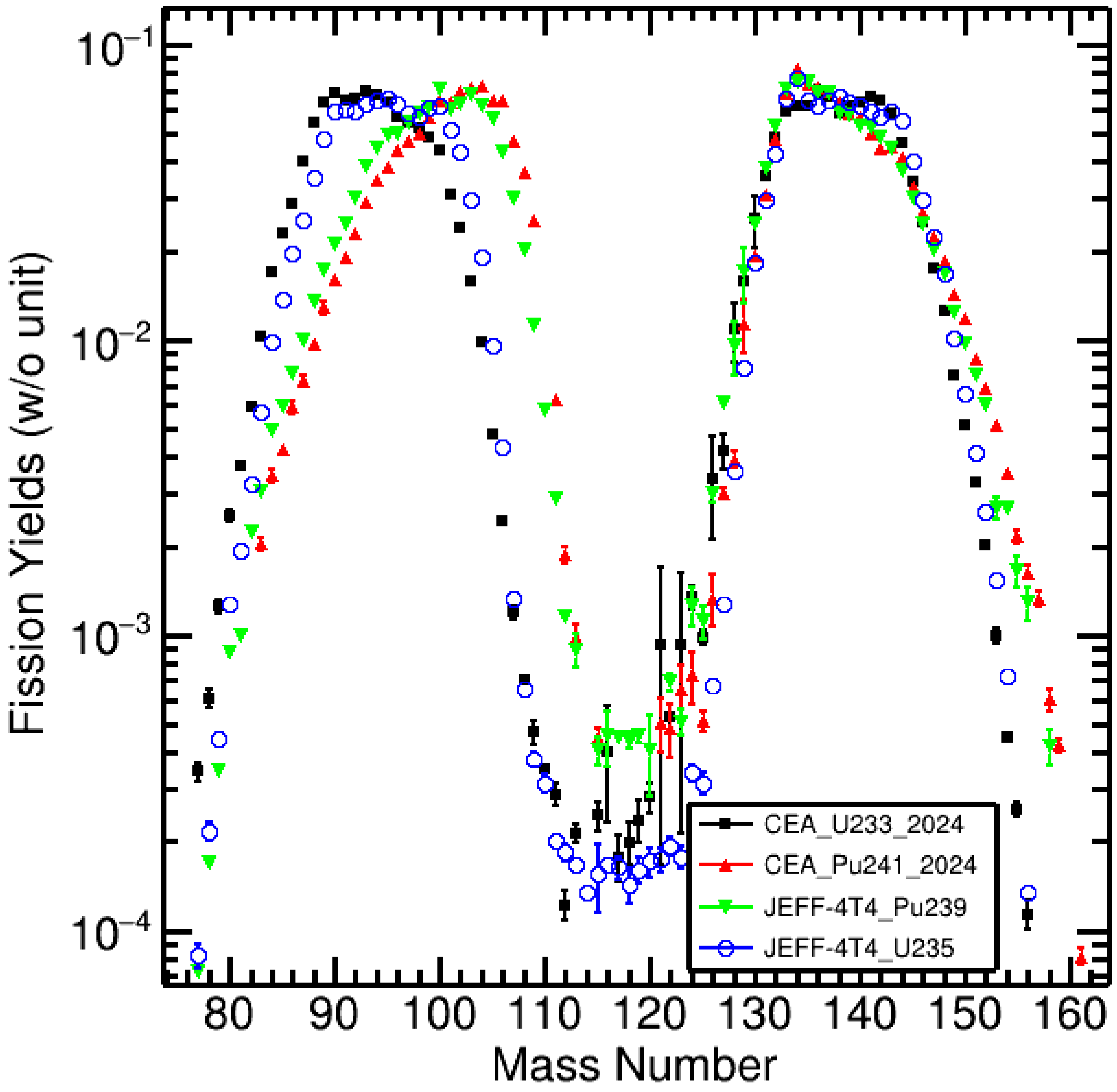


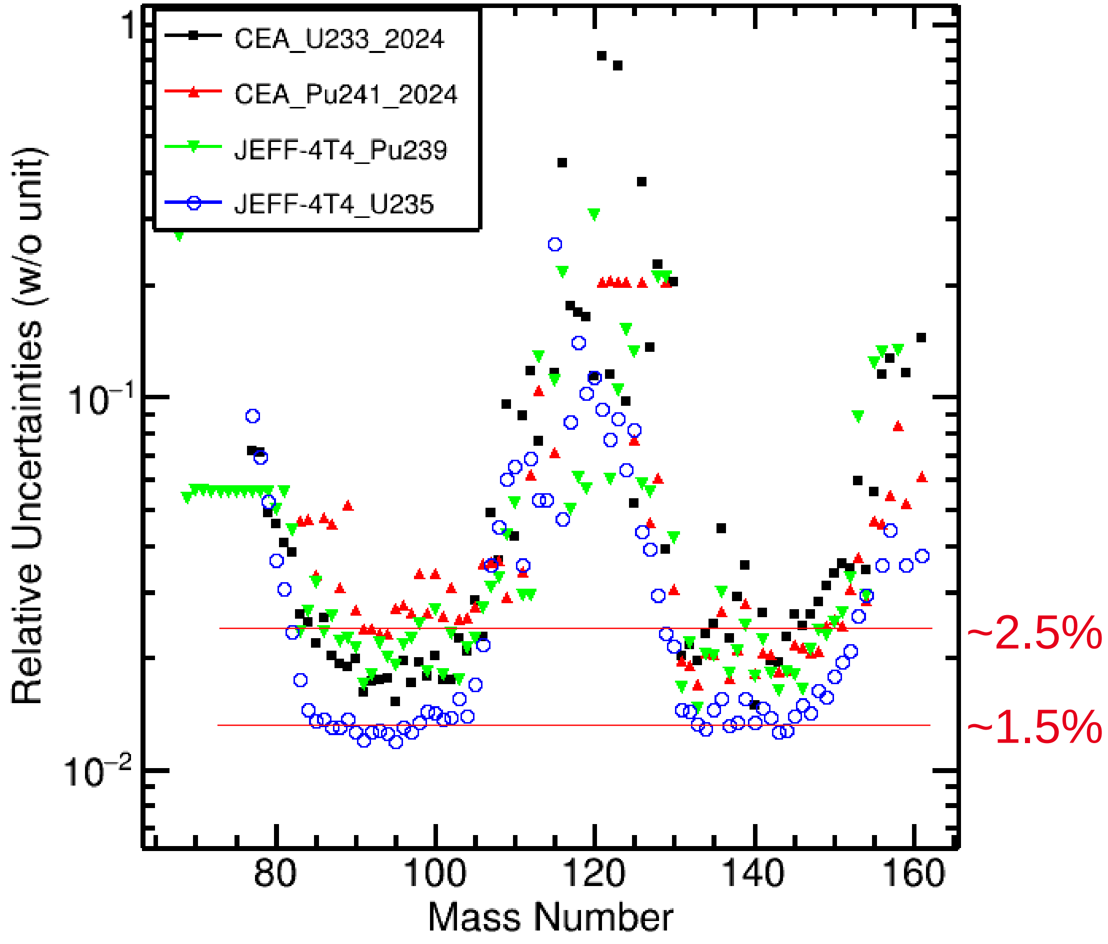
$^{233}U(n_{th},f)$: Chain Yields





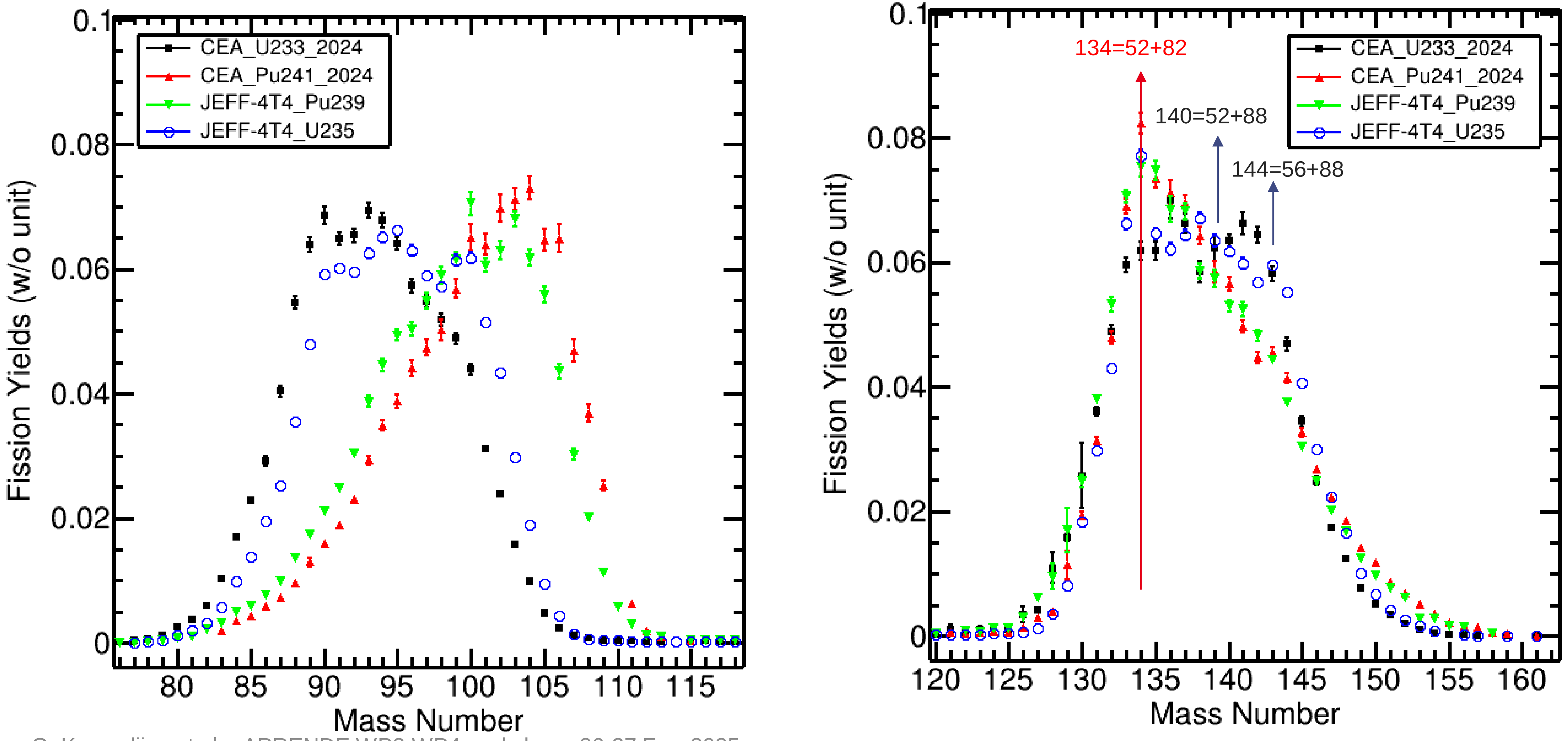
Intercomparison : $^{233}U(n_{th},f)$ - $^{235}U(n_{th},f)$ - $^{239}Pu(n_{th},f)$ - $^{241}Pu(n_{th},f)$





Intercomparison : $^{233}U(n_{th},f)$ - $^{235}U(n_{th},f)$ - $^{239}Pu(n_{th},f)$ - $^{241}Pu(n_{th},f)$

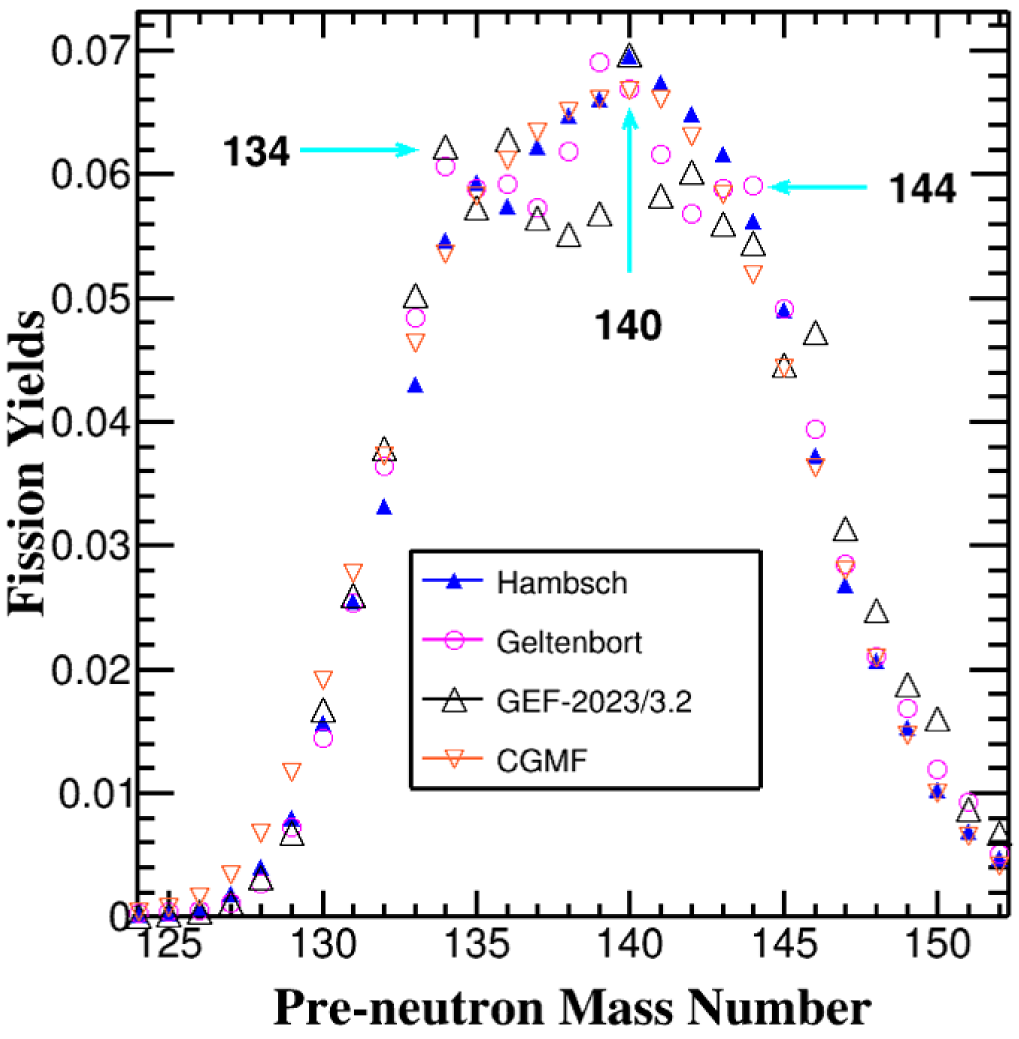
→ New evaluated database – free of model input- – in order to test phenomenological fission models

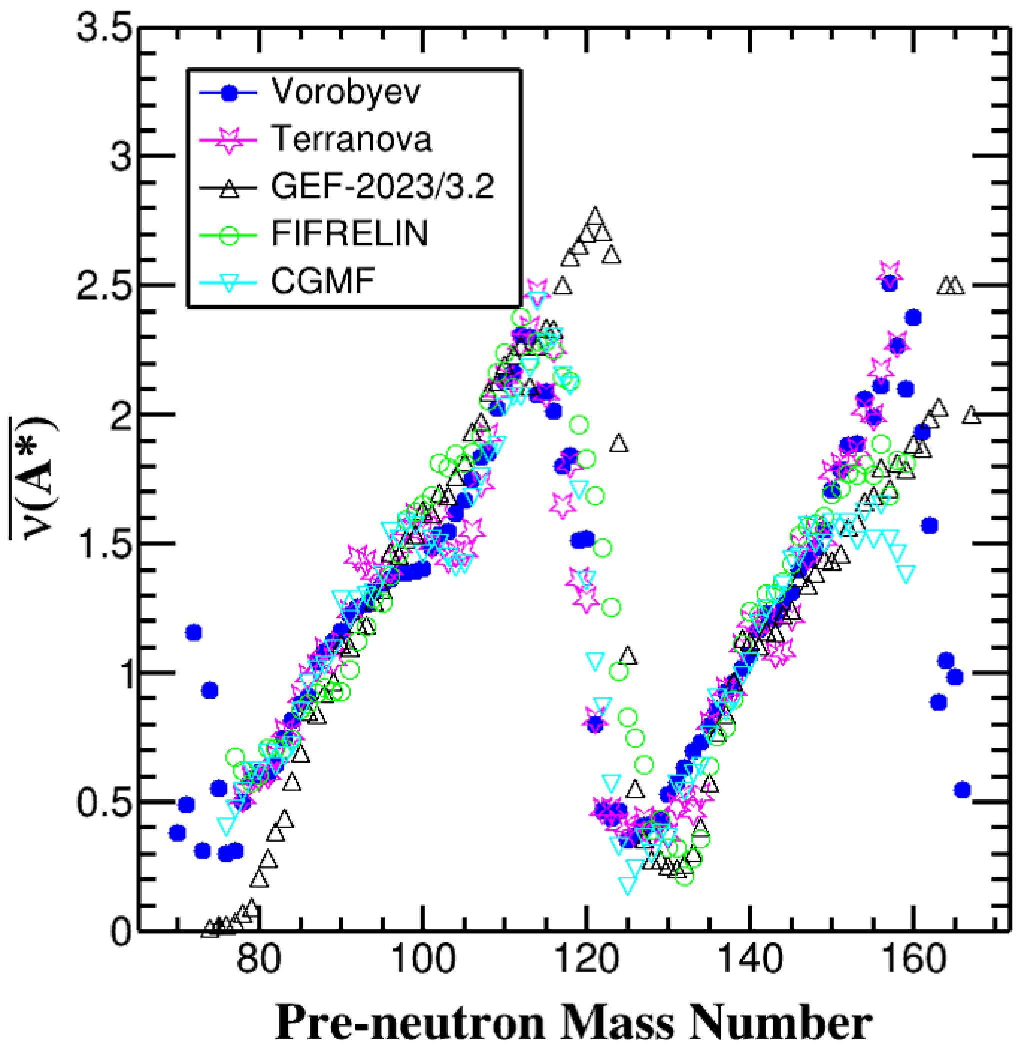


$^{235}U(n_{th},f)$: From pre-n yields to post-n yields

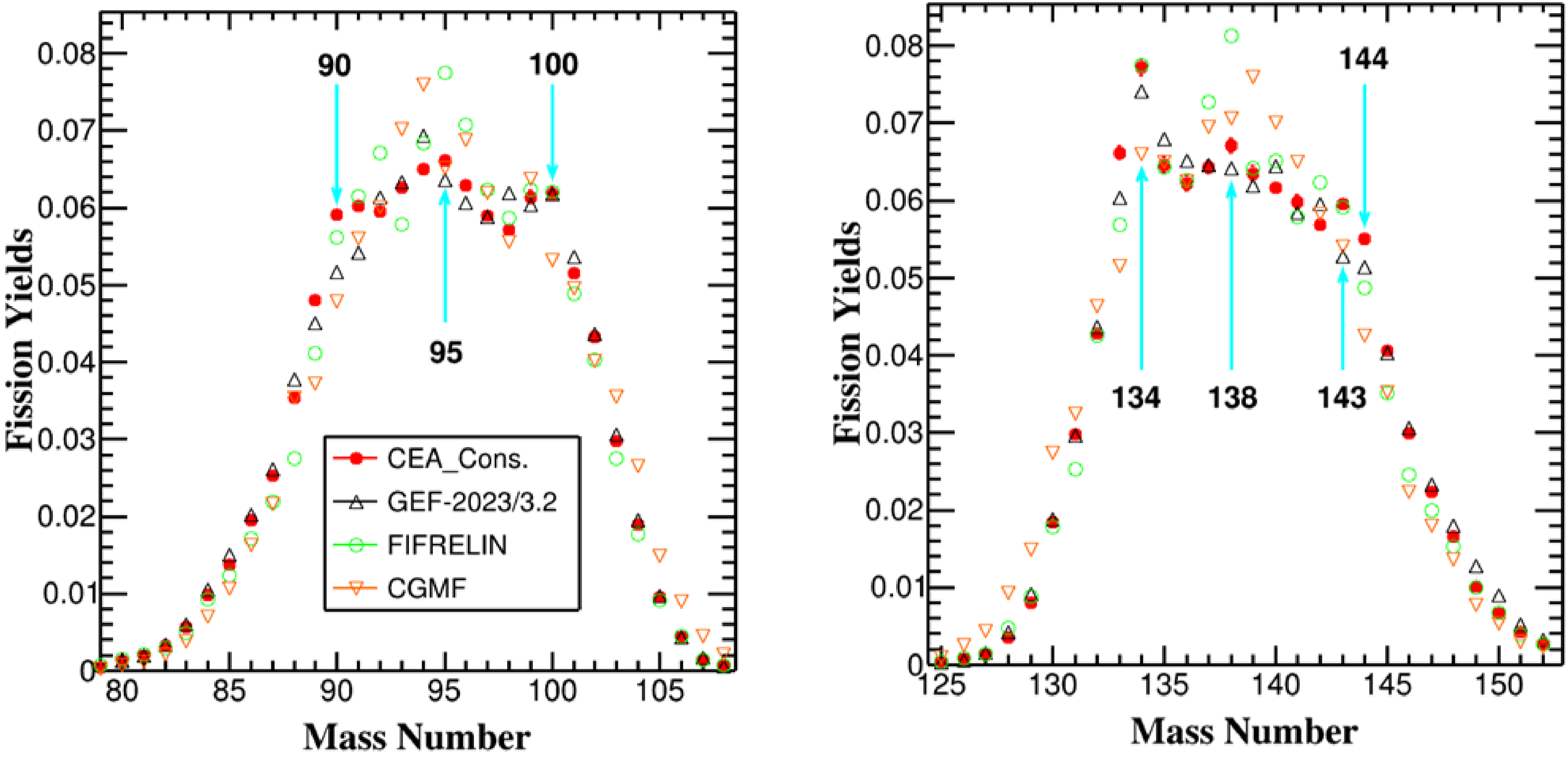
$$Y_A = \sum_{\nu=0} Y_{A^*} \cdot P(\nu \mid A^*) \quad \text{with} \quad A^* = A + \nu$$

$^{235}U(n_{th},f)$: From Pre-neutron yields to post-neutron yields

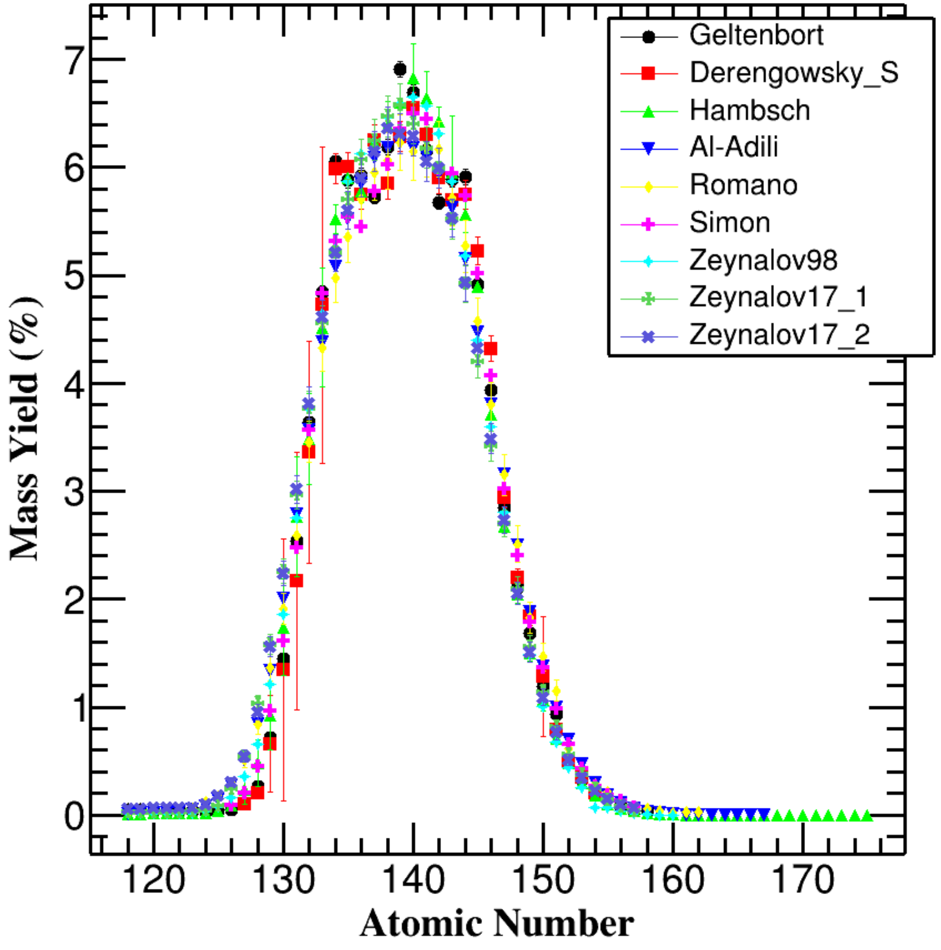


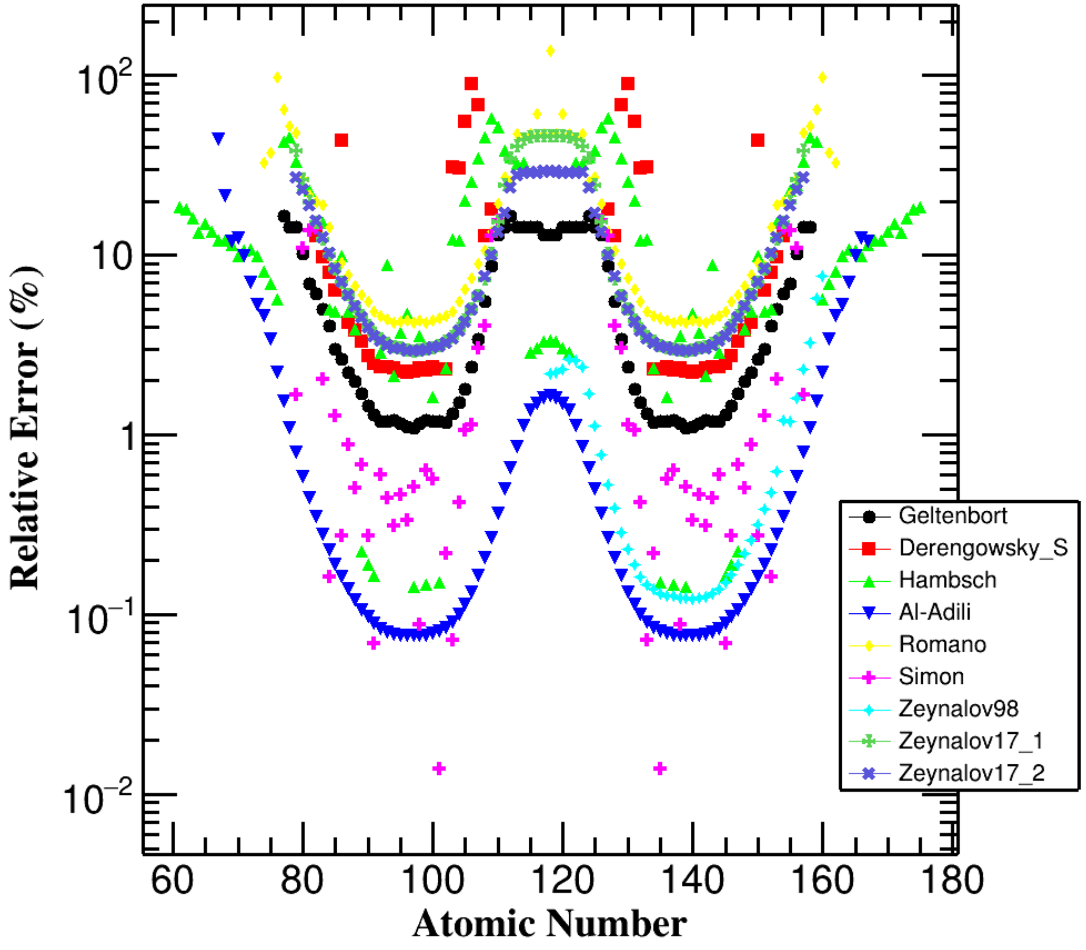


$^{235}U(n_{th},f)$: From Pre-neutron yields to post-neutron yields → comparison to codes

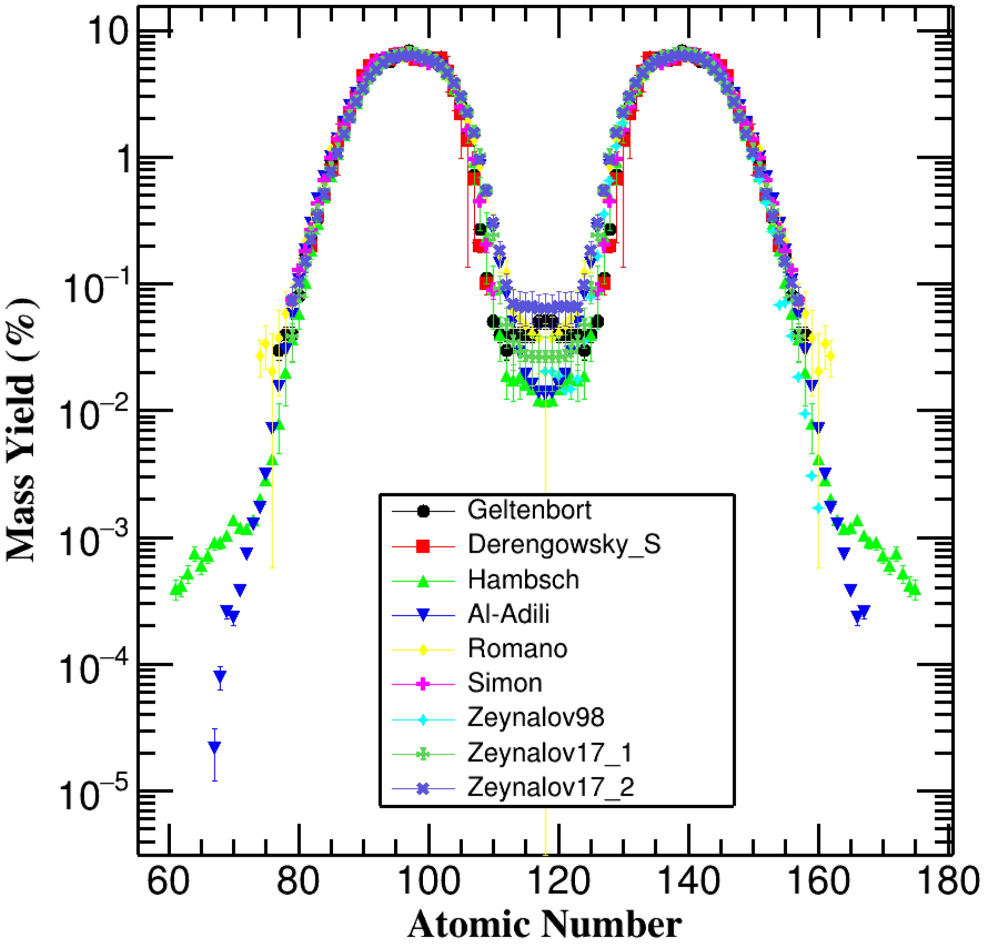


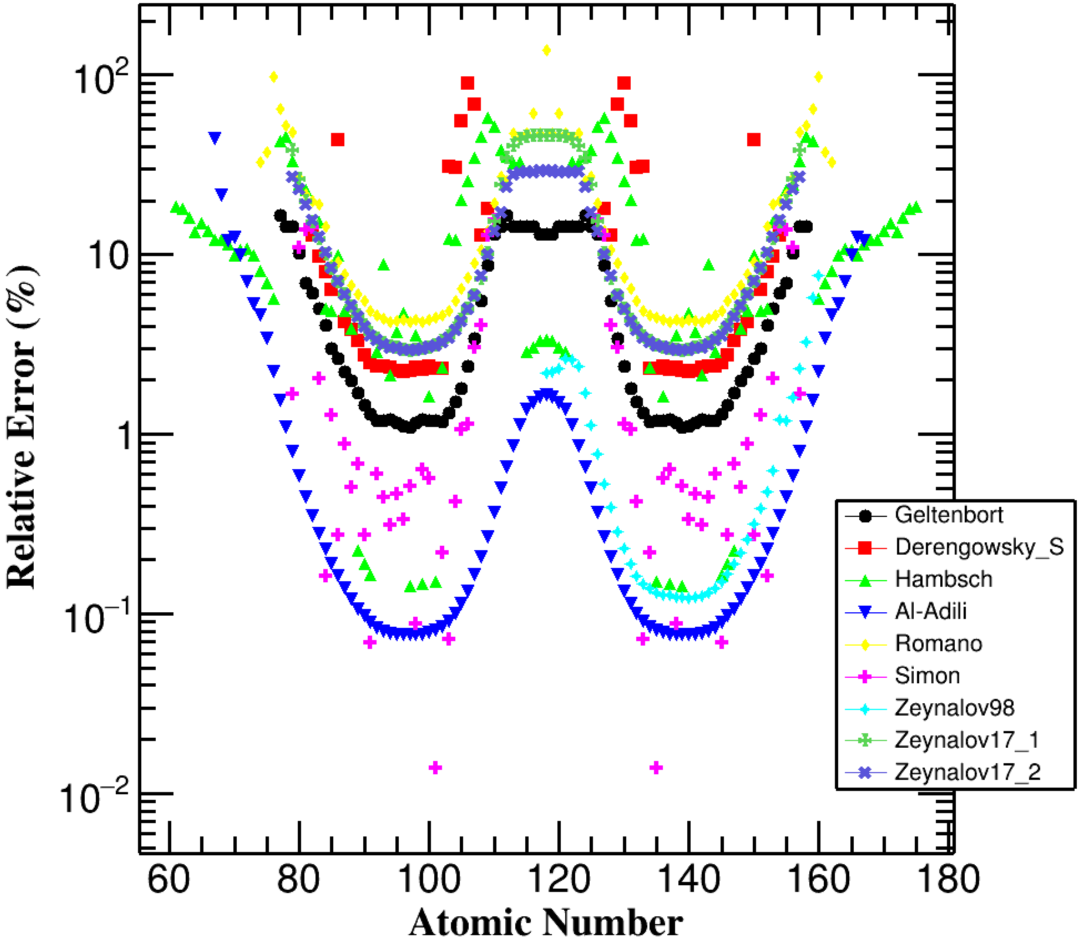
$^{235}U(n_{th},f)$: Pre-neutron yields → experimental data





$^{235}U(n_{th},f)$: Pre-neutron yields → experimental data

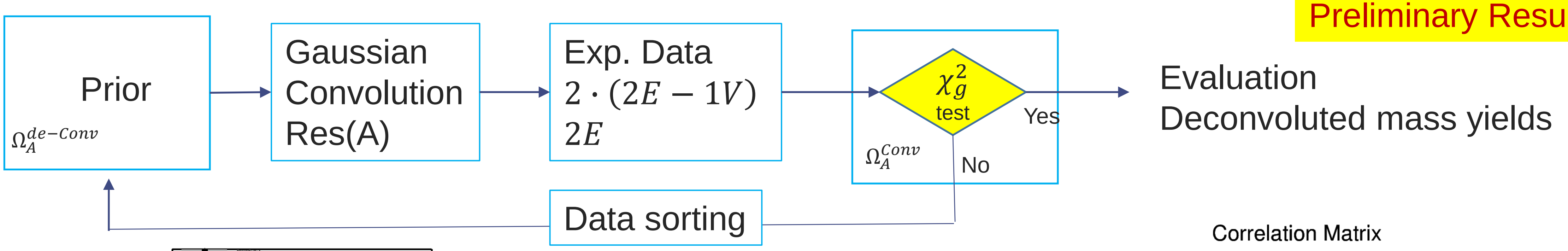


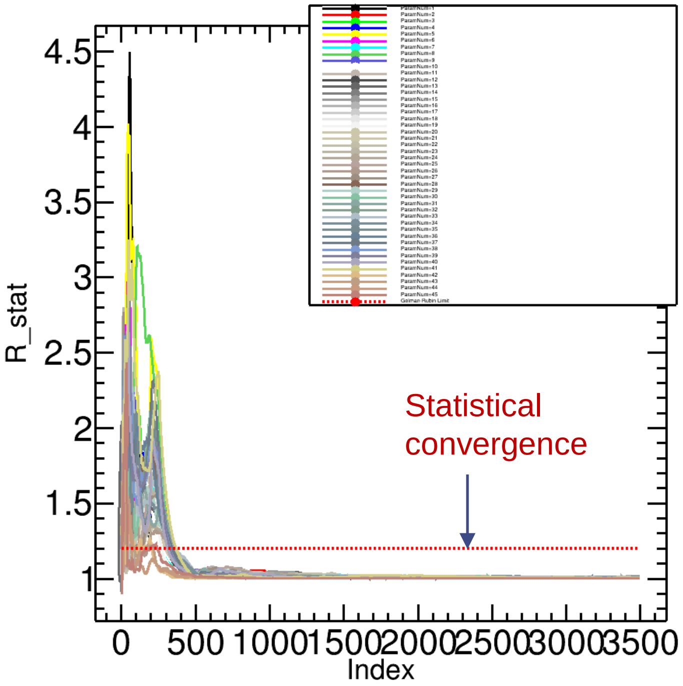


A. Regonesi PhD Thesis (2024-2027)

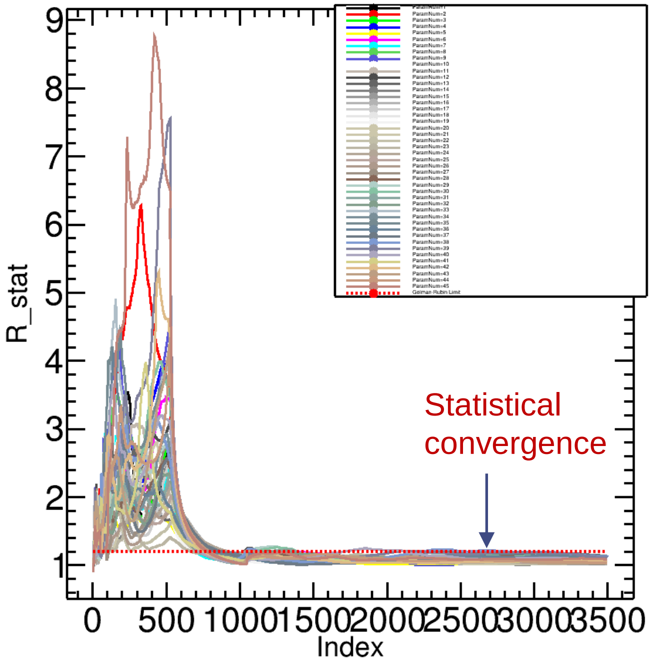
$^{235}U(n_{th},f)$: pre-n mass yield analysis → MCMC method

Preliminary Results

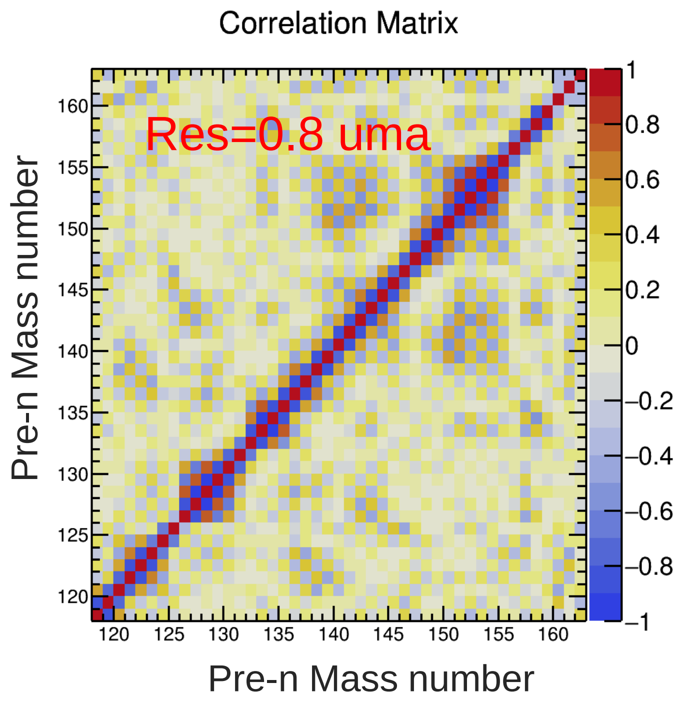




$2 \cdot (2E - 1V)$ Exp. Data



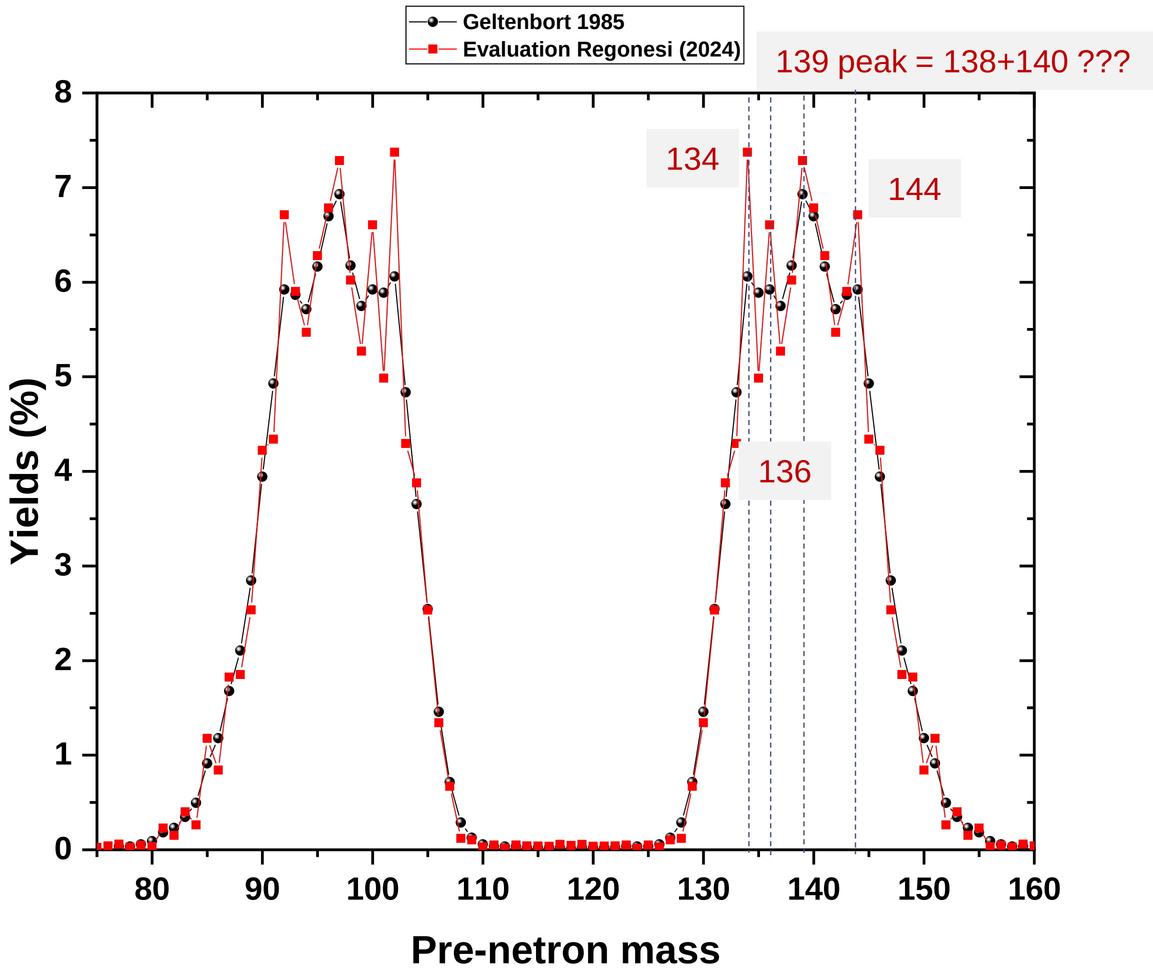
All Exp. Data

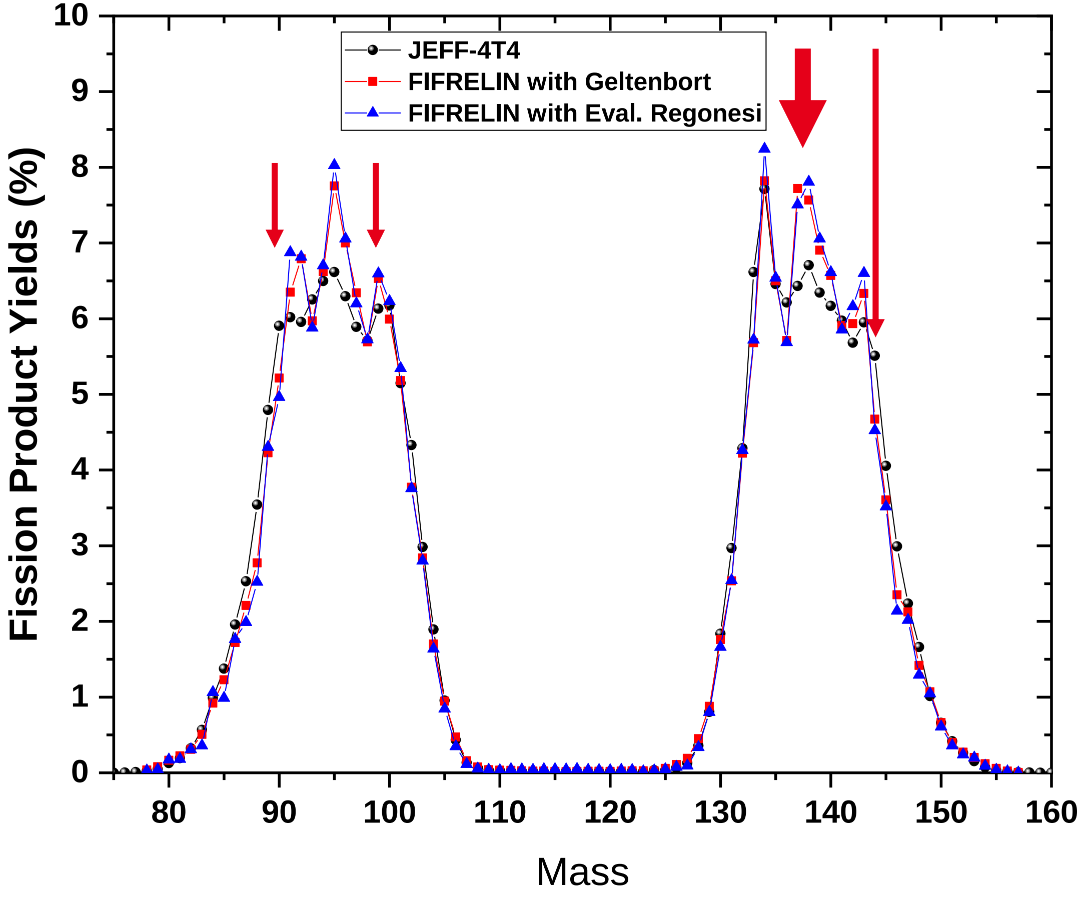


A. Regonesi PhD Thesis (2024-2027)

Perspectives : pre-n mass yield analysis → MCMC method

Preliminary Results





Geltenbort's data : Exp. Resolution Res(A)~0.8 uma

A. Regonesi PhD Thesis (2024-2027)

Conclusion and perspectives

- Consistent evaluation of Mass – Independant – Cumulative – Chain yields $^{233,\,235}U(n_{th},f)$ & $^{229,\,241}Pu(n_{th},f)$
- ^{235}U & ^{239}Pu FY ENDF files are available in JEFF-4T4 Library
- ^{233}U & ^{241}Pu FY ENDF files should be available in February 2025
- Tractability of the selected and used data is available

  → reinterpretation of EXP data with correlation matrix : must be preserved for the future !

- PhD thesis @ Cadarache (A. Regonesi 2024-2027) is ongoing :

  → Pre-n yield evaluation
  → prompt neutron emission evaluation per mass evaluation
  } Combined analysis to post-n evaluation

  → neutron energy dependent fission yield studies : ^{235}U, ^{238}U …

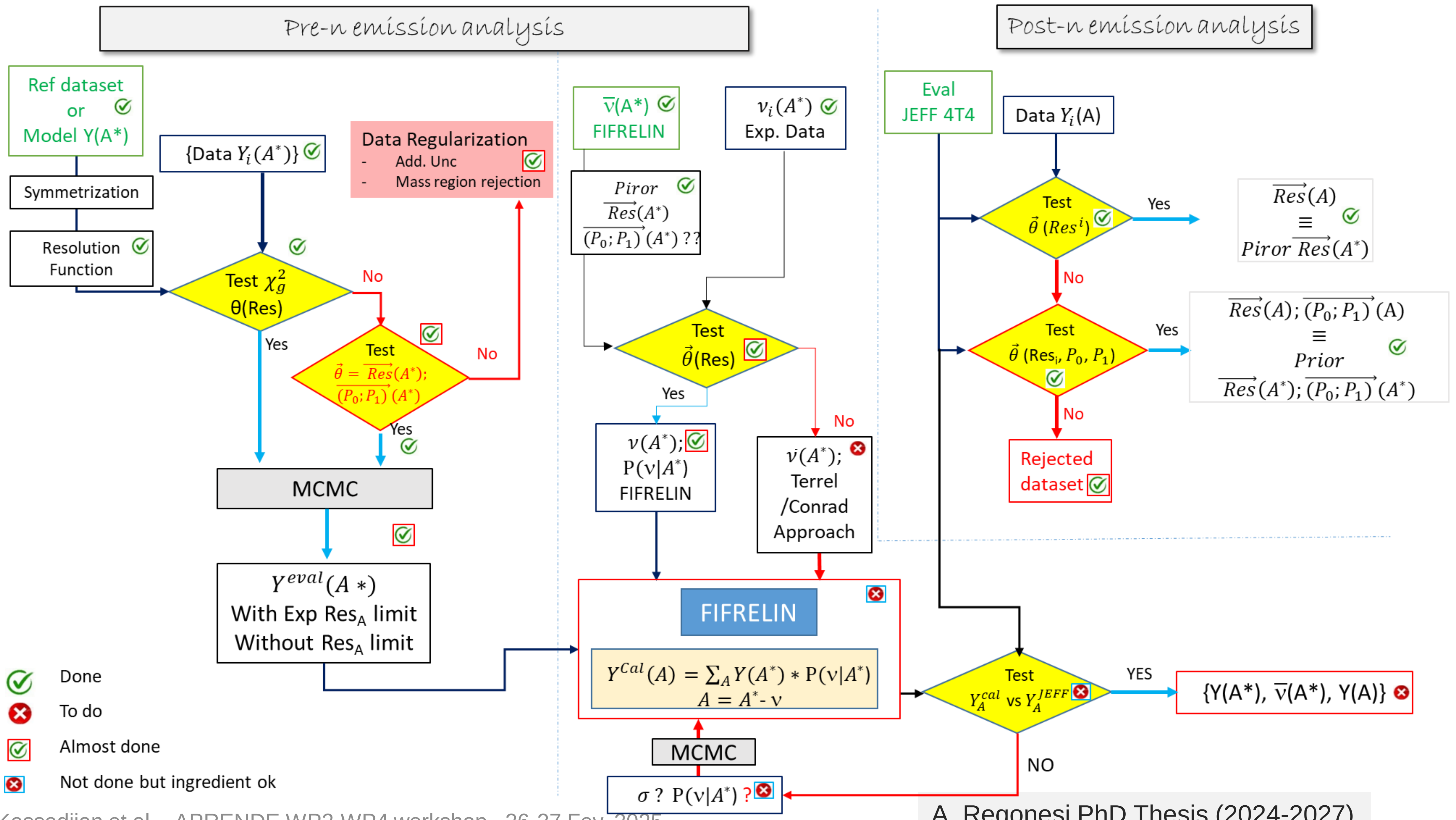
- Middle term perspectives correspond to the use of the new Charge distribution per mass with the correlation matrix from the Direct-Zp model based on pre-neutron parameters (replacing the Wahl Systematics)

  → Results from Sidi. M. Cheikh Thesis → JEFF-4.1

  → New PhD project (2025-2028) on P(Z|A) and cumulative yields should be start.

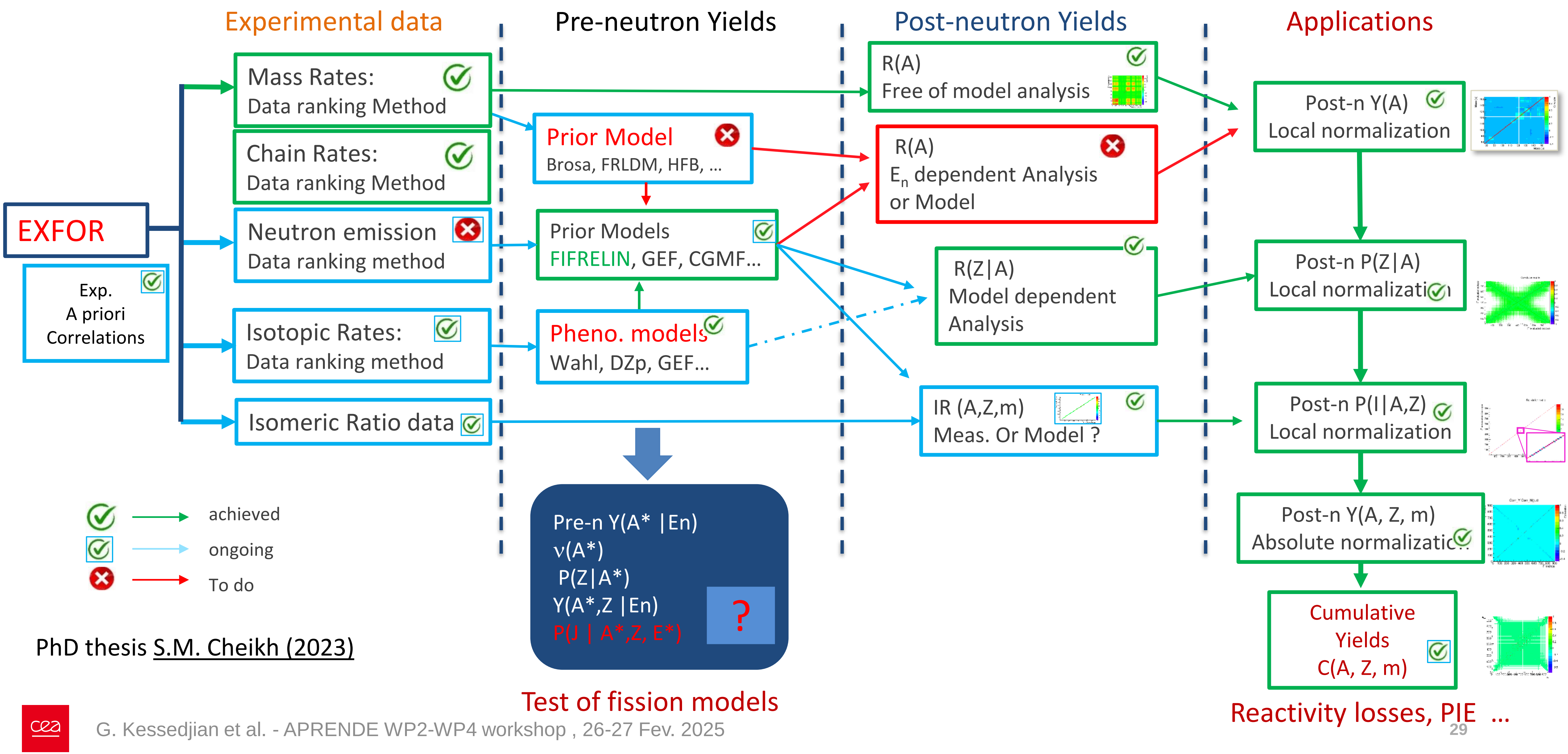
Perspectives : pre-n mass yield analysis → MCMC method

Preliminary Results



A. Regonesi PhD Thesis (2024-2027)

JEFF-4 Goal → New methodology : complete and consistent



PhD thesis S.M. Cheikh (2023)

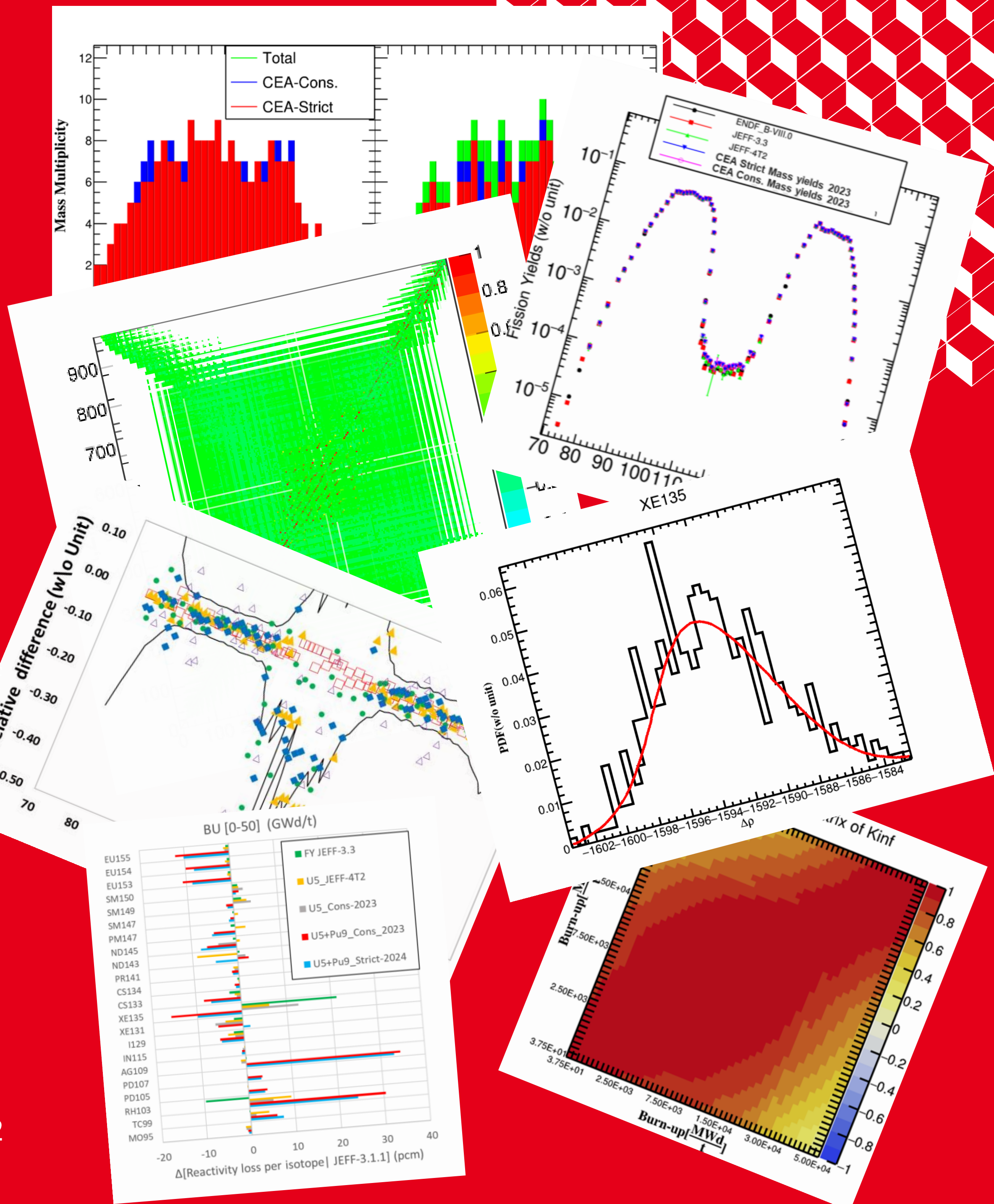
G. Kessedjian[1], A. Regonesi[1], N. Teixeira-Rua[1], S. M. Cheikh[1], O. Serot[1], A. Chebboubi[1], D. Bernard[1]

[1] CEA, DES, IRESNE, DER, SPRC, LEPh, Cadarache center, F-13108 Saint Paul lez Durance, France

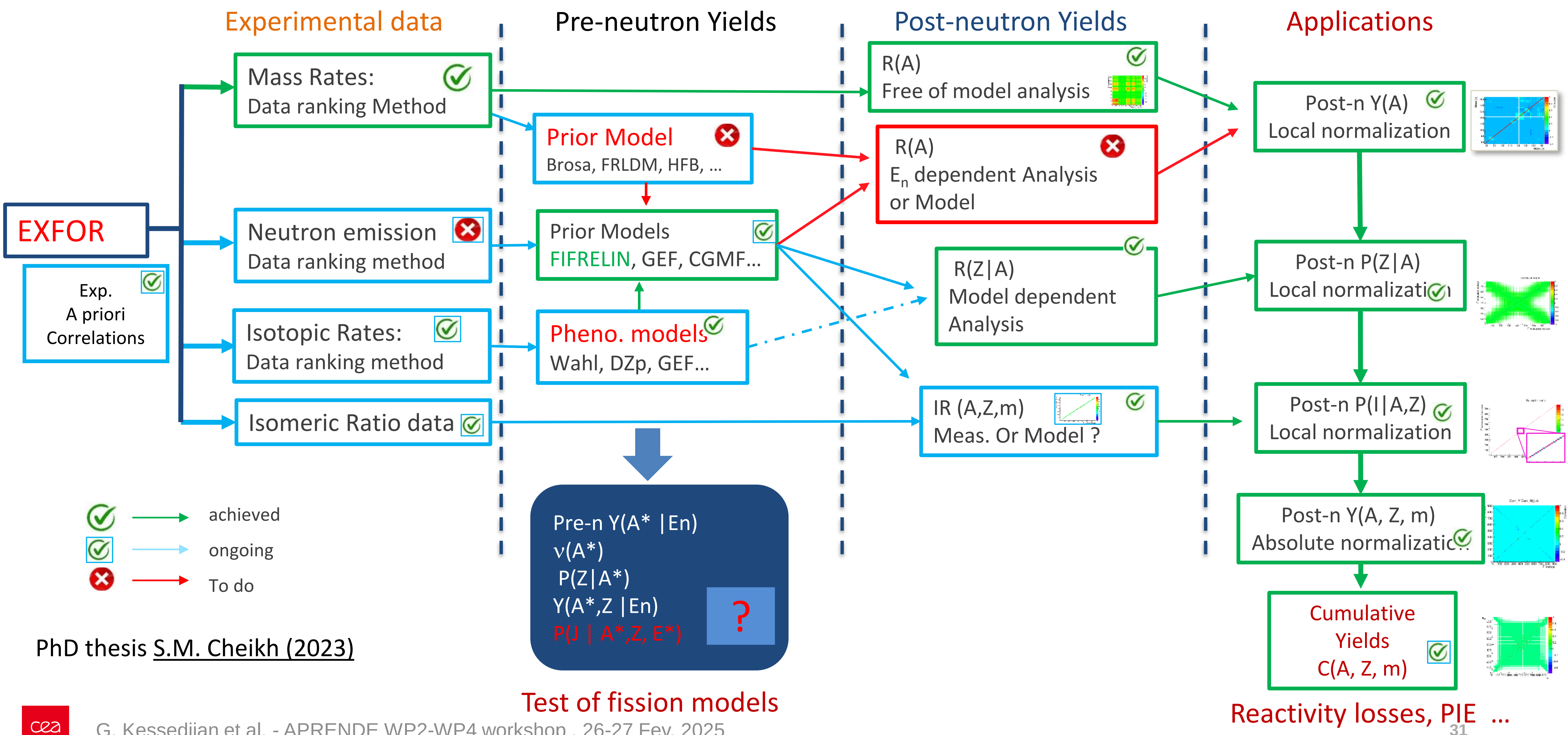
jefdoc-1902
jefdoc-1982
jefdoc-2007
jefdoc-2038
jefdoc-2056
jefdoc-2027
jefdoc-2203
jefdoc-2204
jefdoc-2205
jefdoc-2207
jefdoc-2247
jefdoc-2295
jefdoc-2296
jefdoc-2370
jefdoc-2371
jefdoc-2372

Thank you for your attention

- B. Voirin, G. Kessedjian et al, EPJ N - Nuclear Sciences & Technologies, EDP Sciences, 4, pp.26 (2018)
- G. Kessedjian, S.-M. Cheikh et al., FPY 2019, Santa Fe, EPJ Web of Conferences 242, 05001 (2020)
- S.-M. Cheikh, G. Kessedjian et al., Covariance Workshop 2022, Tokyo, Japan, EPJ Web of Conferences 281, 00023 (2023)
- G. Kessedjian, S.-M. Cheikh et al., Covariance Workshop 2022, Tokyo, Japan, EPJ Web of Conferences 281, 00022 (2023)
- S.-M. Cheikh, G. Kessedjian et al., M&C2023 conference, Niagara Falls, Canada (2023)
- S.-M. Cheikh, G. Kessedjian et al., M&C2023 proceedings
- S-M Cheikh, G. Kessedjian et al., NSE 2024, 1–14. https://doi.org/10.1080/00295639.2024.2347693
- S.-M. Cheikh, PhD thesis, UGA, 18 Oct. 2023
- S.-M. Cheikh, G. Kessedjian et al., Eur. Phys. J. A, 60 11 (2024) 222



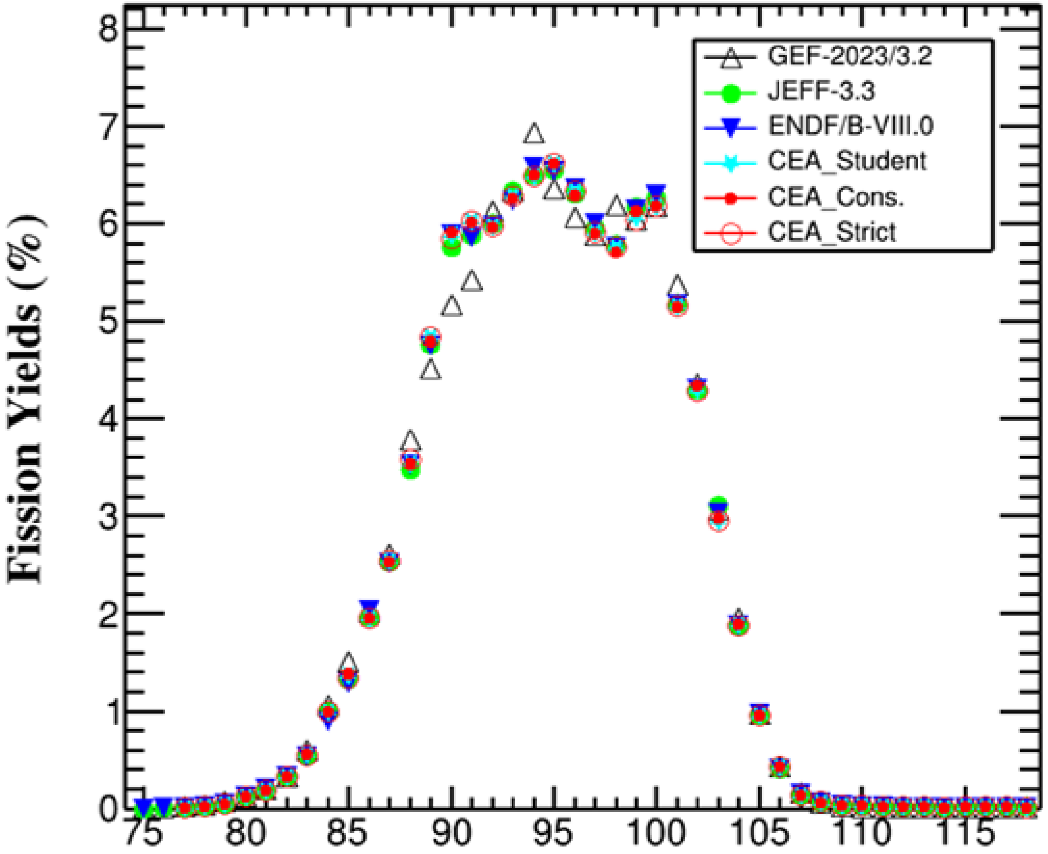
JEFF-4 Goal → New methodology : complete and consistent

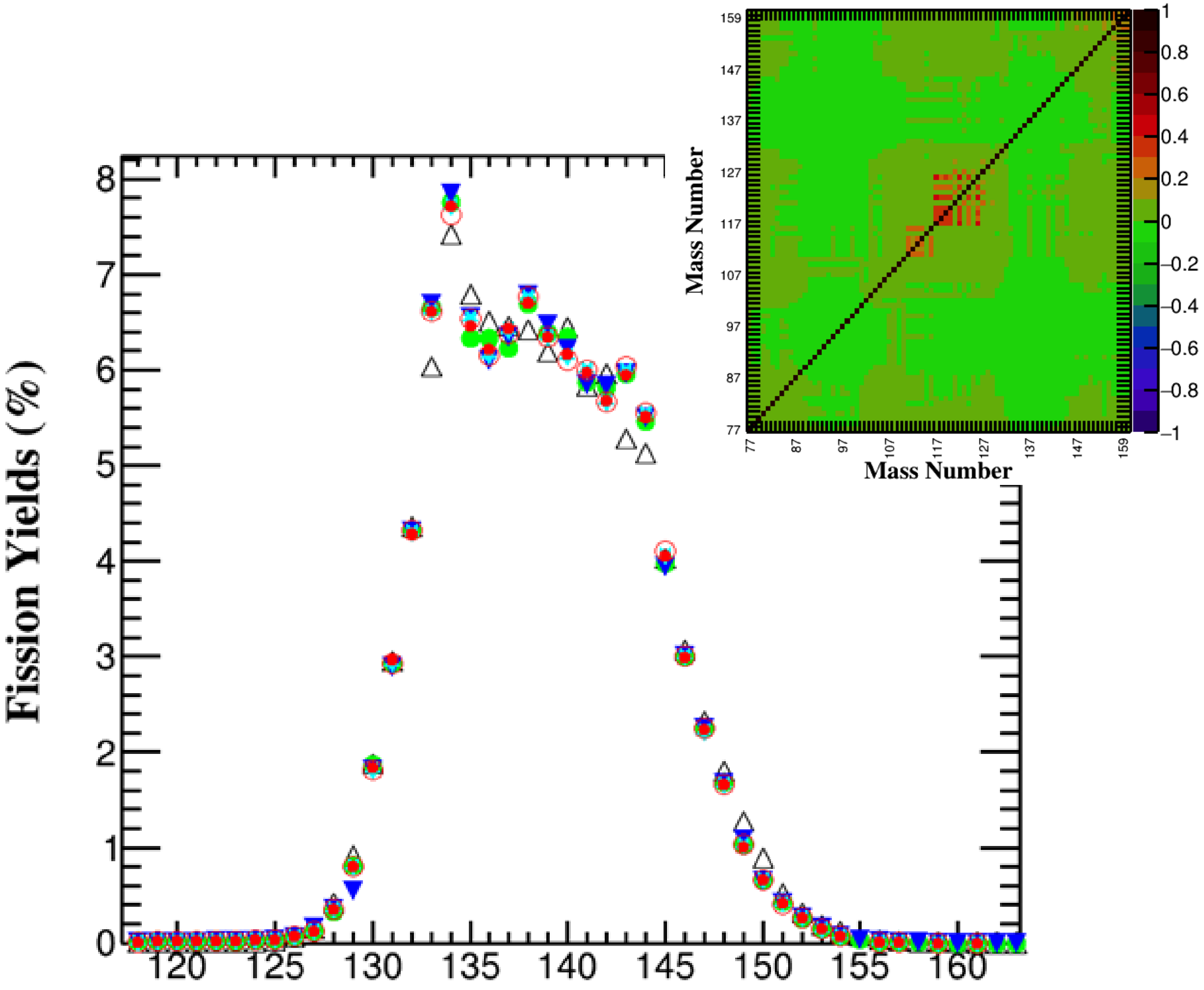


PhD thesis S.M. Cheikh (2023)

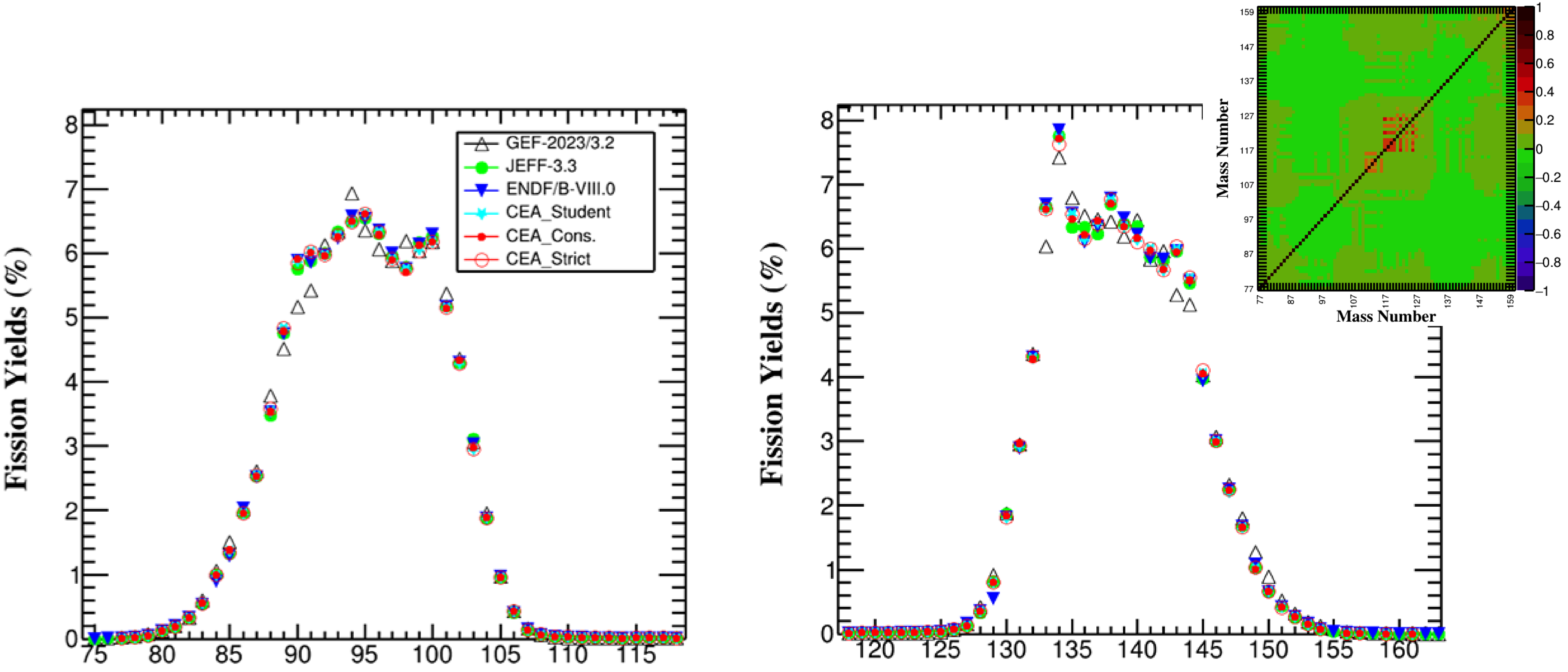
$^{235}U(n_{th},f)$: JEFF-4T4

$^{235}U(n_{th},f)$: JEFF-4T4

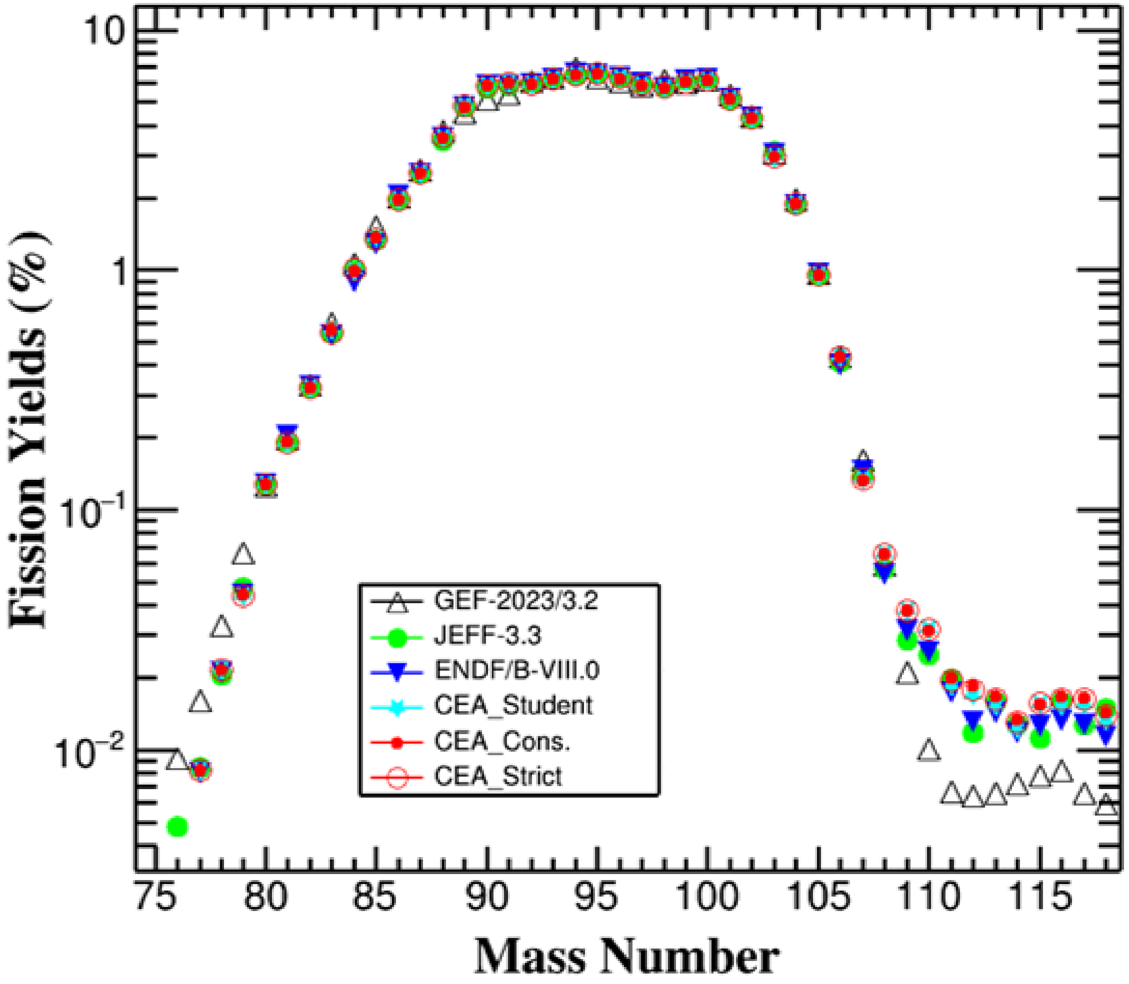


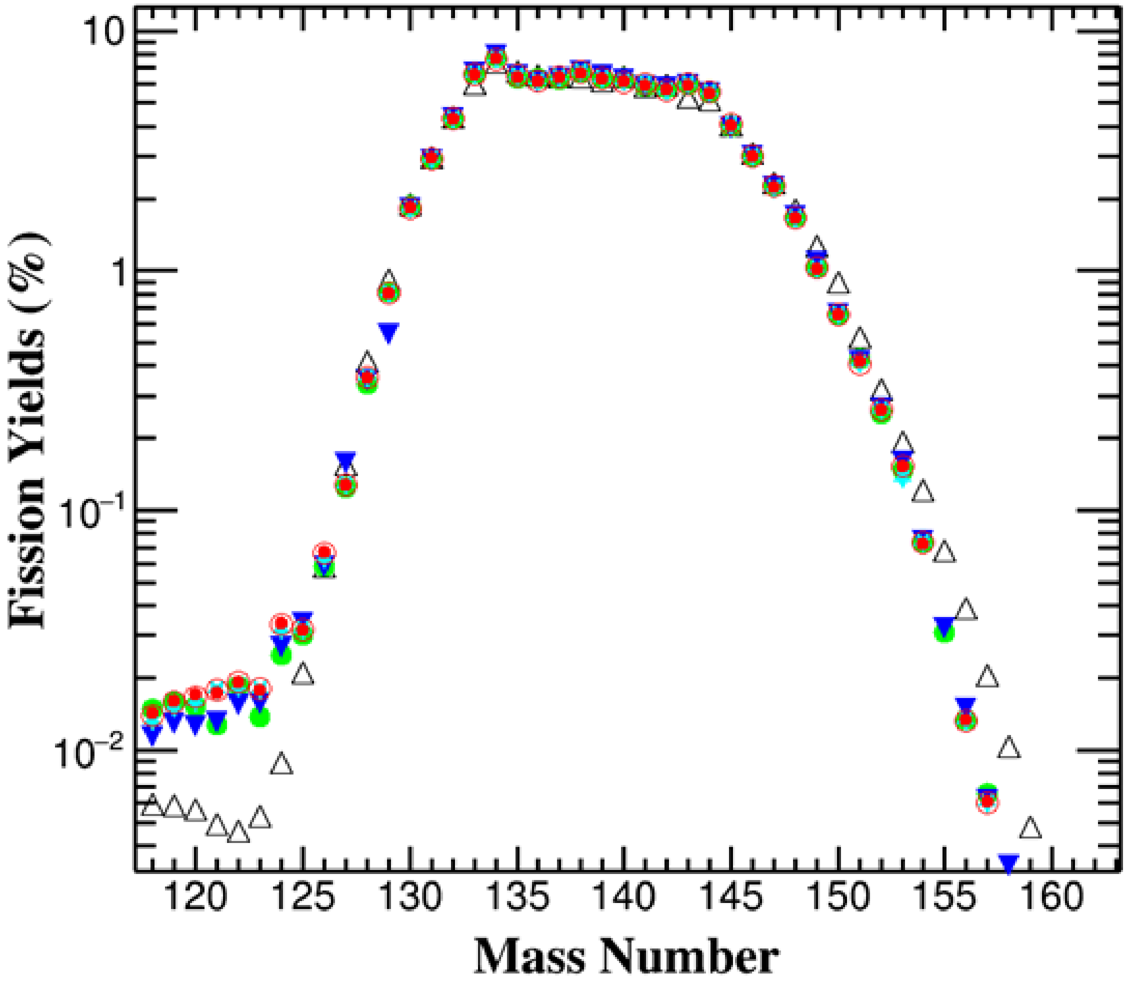


$^{235}U(n_{th},f)$: JEFF-4T4

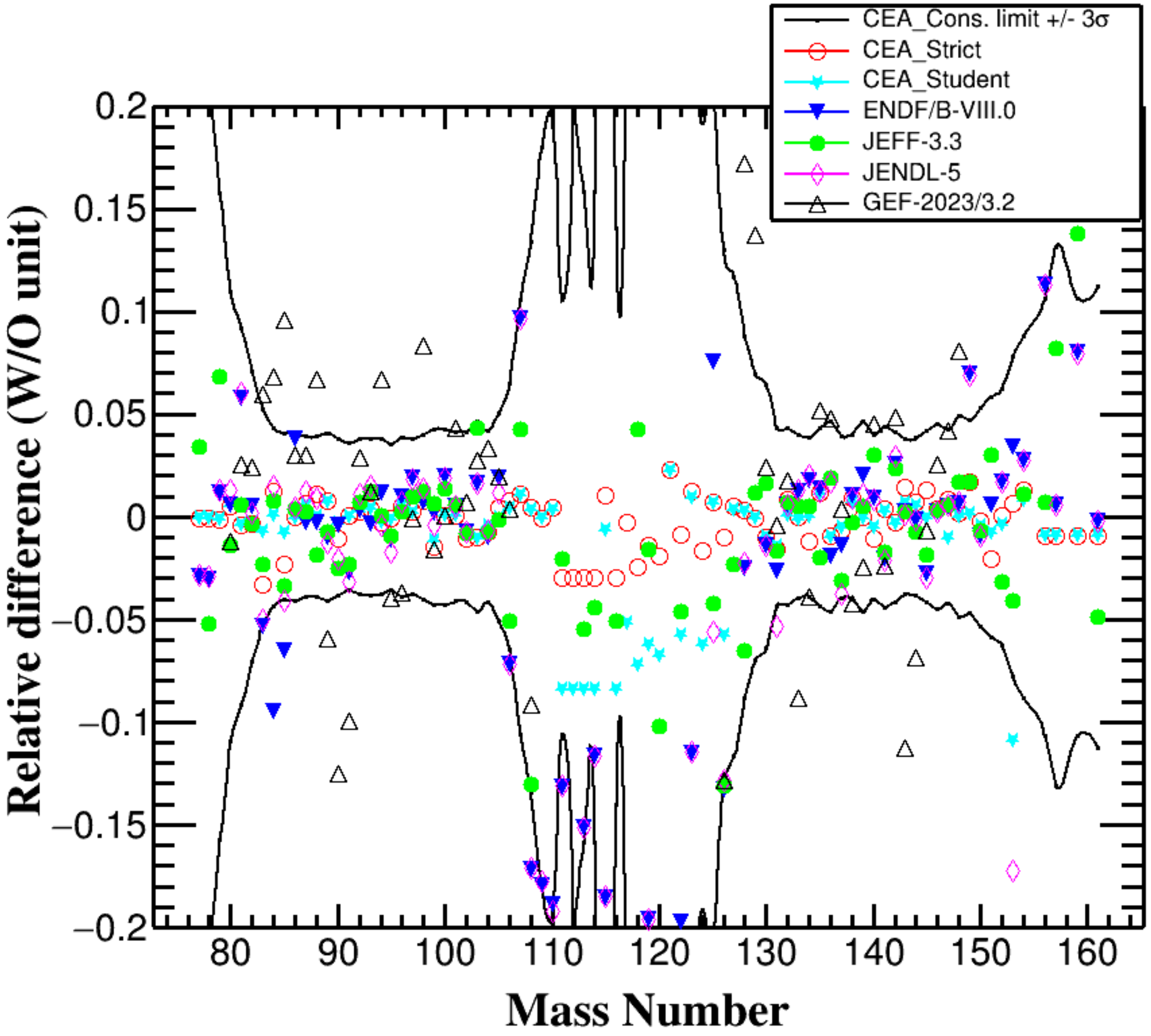


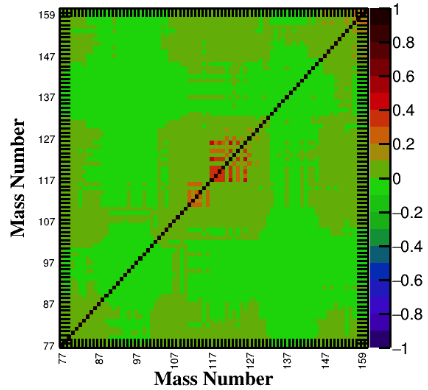
$^{235}U(n_{th},f)$: JEFF-4T4

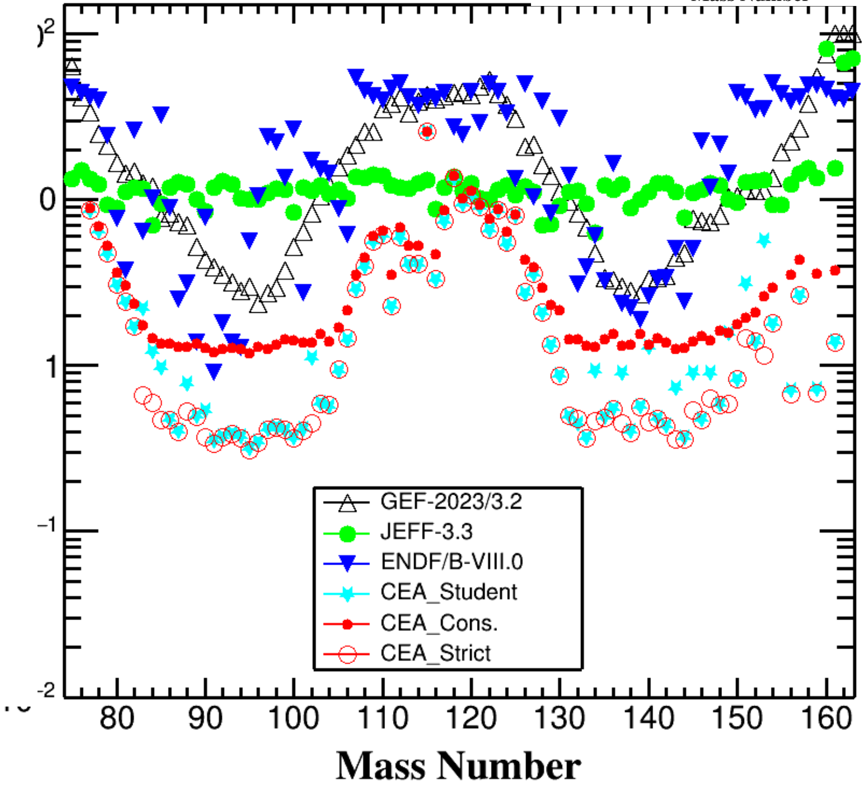




$^{235}U(n_{th},f)$: Exclusion plot in reference to JEFF-4T4 evaluation



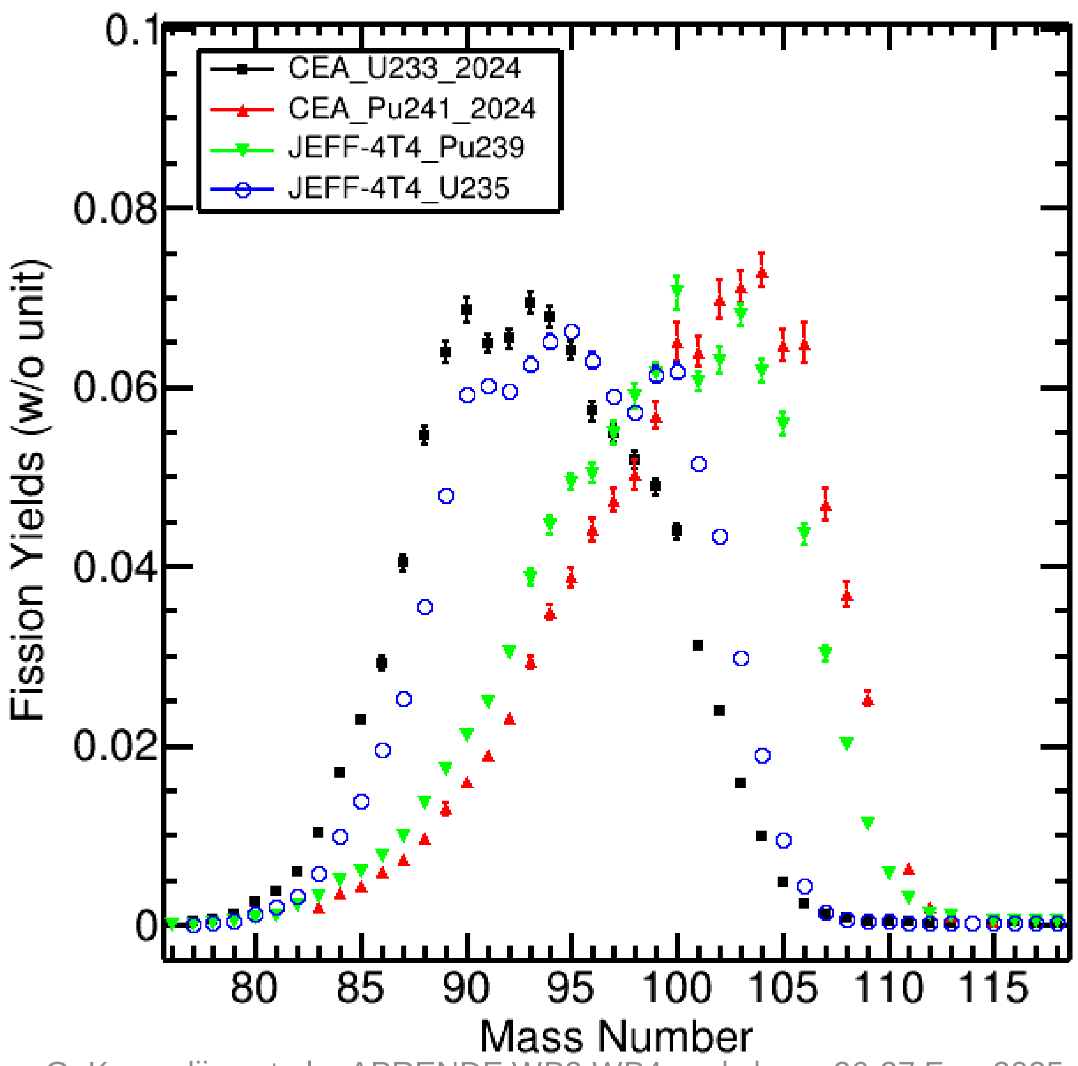


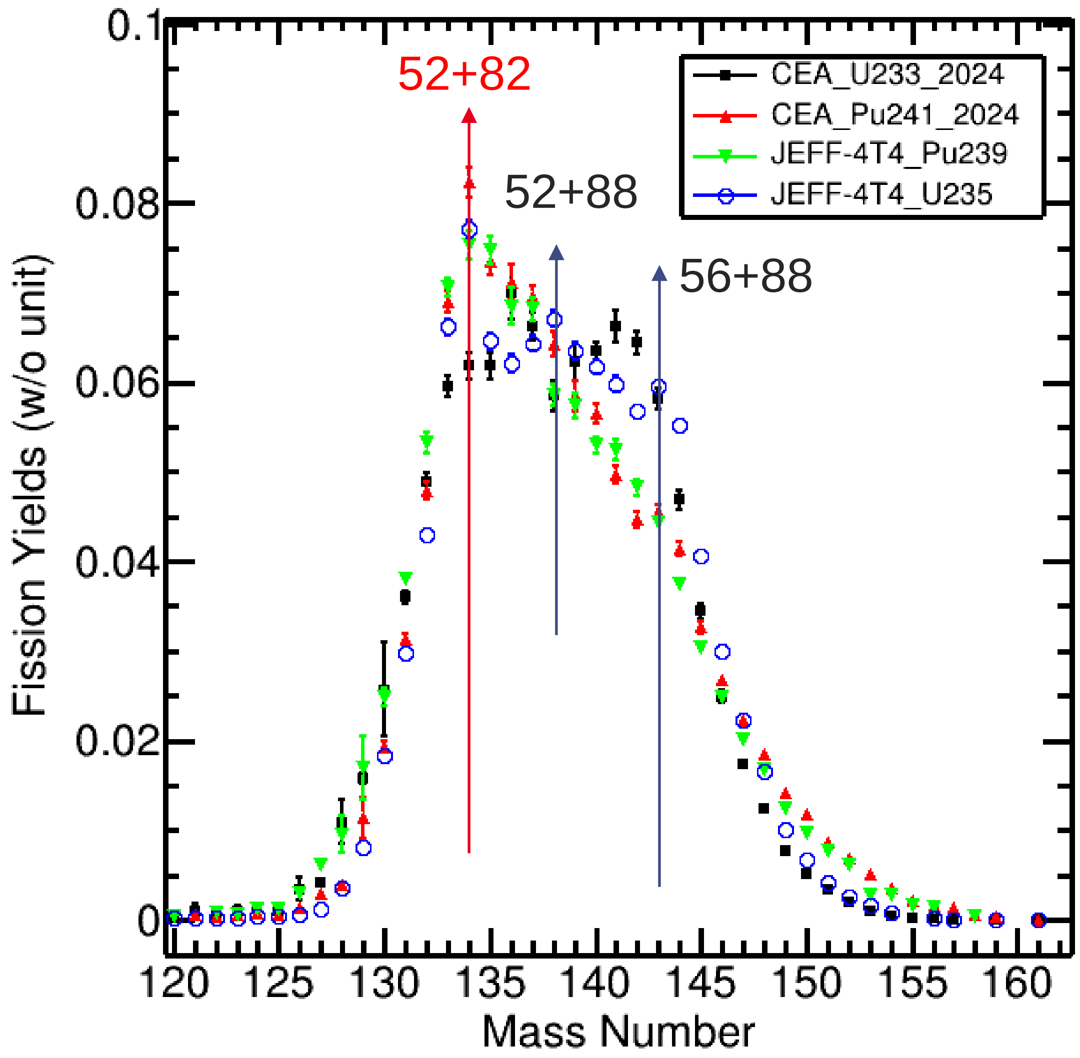


Intercomparison : $^{233}U(n_{th},f)$ - $^{235}U(n_{th},f)$ - $^{239}Pu(n_{th},f)$ - $^{241}Pu(n_{th},f)$

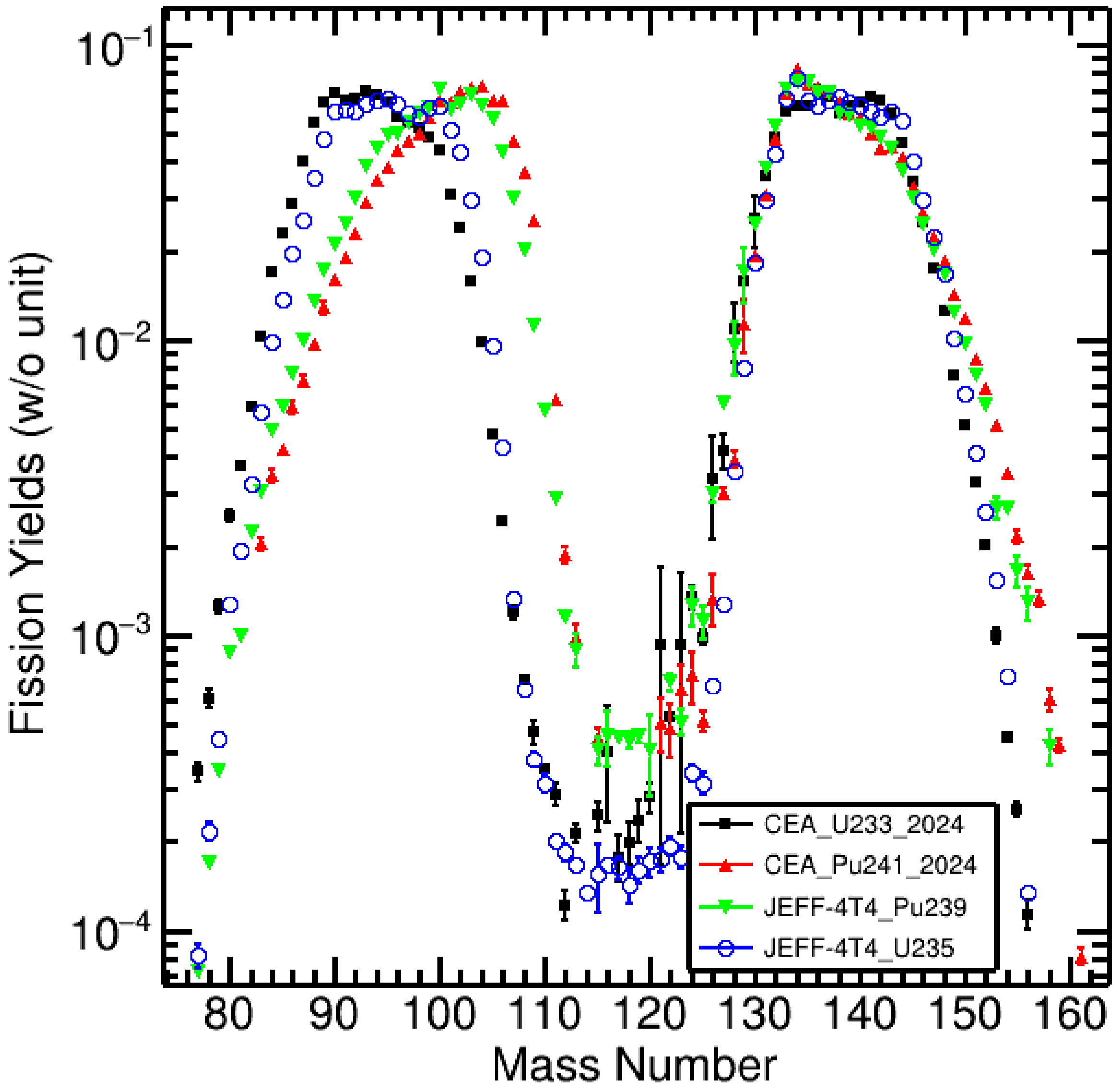
Intercomparison : $^{233}U(n_{th},f)$ - $^{235}U(n_{th},f)$ - $^{239}Pu(n_{th},f)$ - $^{241}Pu(n_{th},f)$

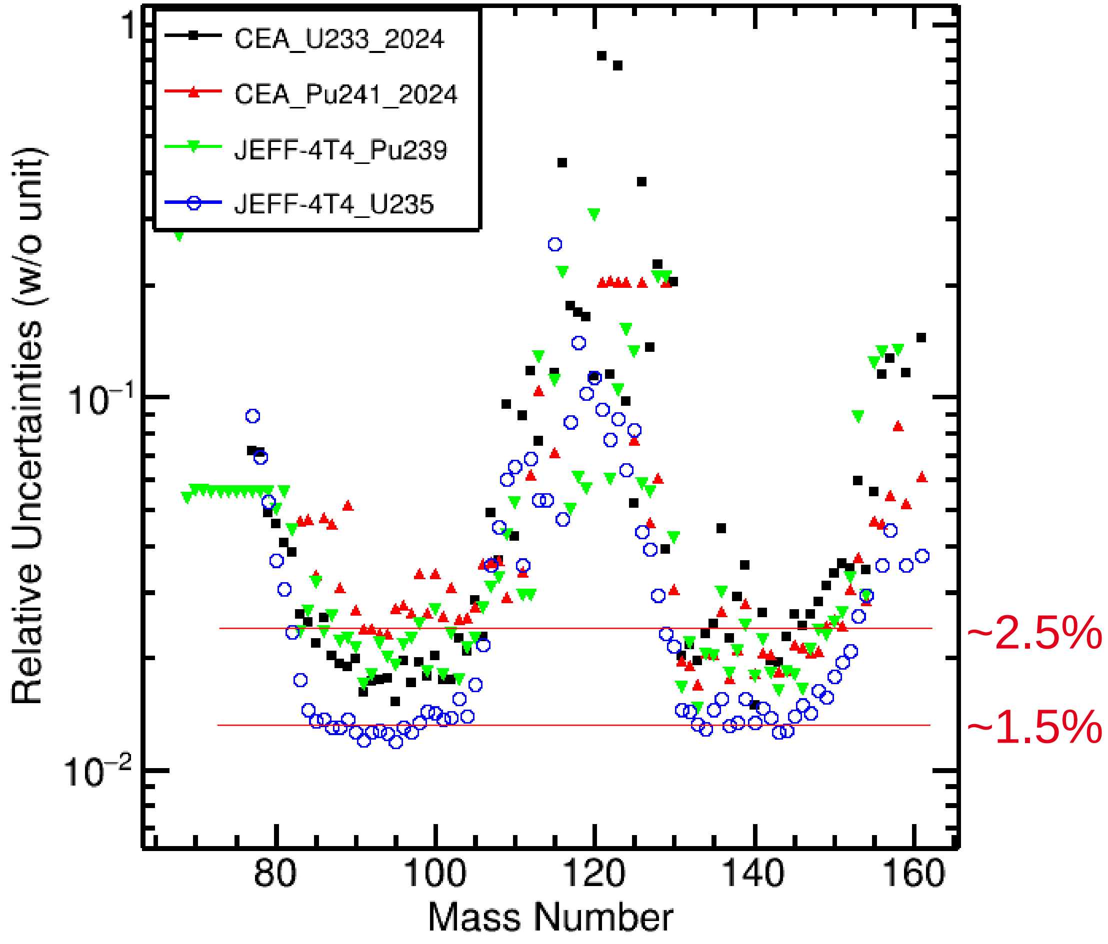
→ New evaluated database – free of model input- – in order to test phenomenological fission models





Intercomparison : $^{233}U(n_{th},f)$ - $^{235}U(n_{th},f)$ - $^{239}Pu(n_{th},f)$ - $^{241}Pu(n_{th},f)$



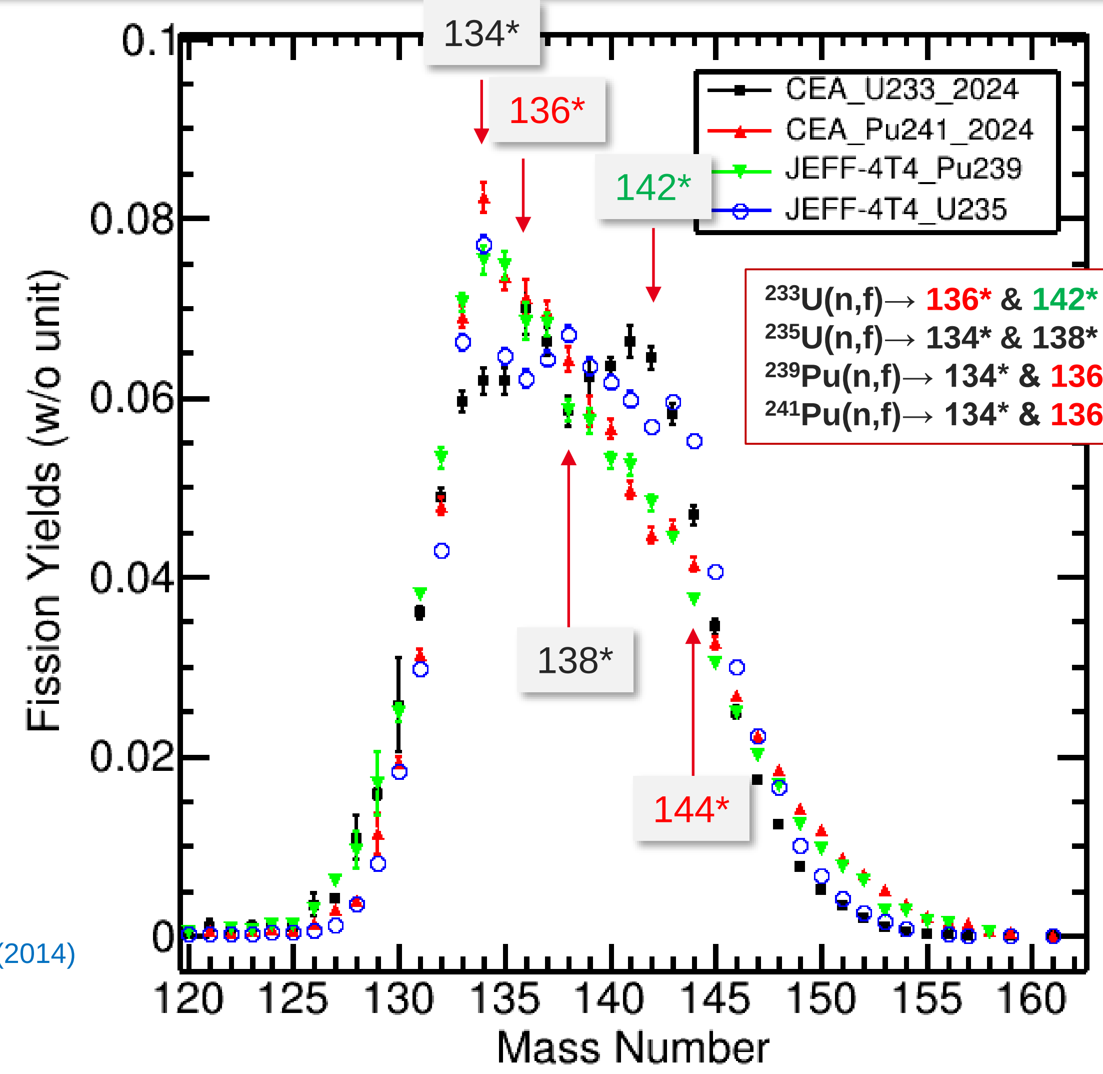


Intercomparison : $^{233}U(n_{th},f)$ - $^{235}U(n_{th},f)$ - $^{239}Pu(n_{th},f)$ - $^{241}Pu(n_{th},f)$

→ New evaluated database – free of model input – in order to test phenomenological fission models

				236U*		240Pu*		242Pu*	
			A,Z	92	236	94	240	94	242
	Z*	N*	A_H*	Z_L	A_L*	Z_L	A_L*	Z_L	A_L*
spheric	50	82	132	42	104	44	108	44	110
oct/sph	52	82	134	40	102	42	106	42	108
oct	52	84	136	40	100	42	104	42	106
Quad	50	88	138	42	98	44	102	44	104
Oct/sph	56	82	138	36	98	38	102	38	104
oct	52	88	140	40	96	42	100	42	102
oct	56	84	140	36	96	38	100	38	102
oct	56	88	144	36	92	38	96	38	98

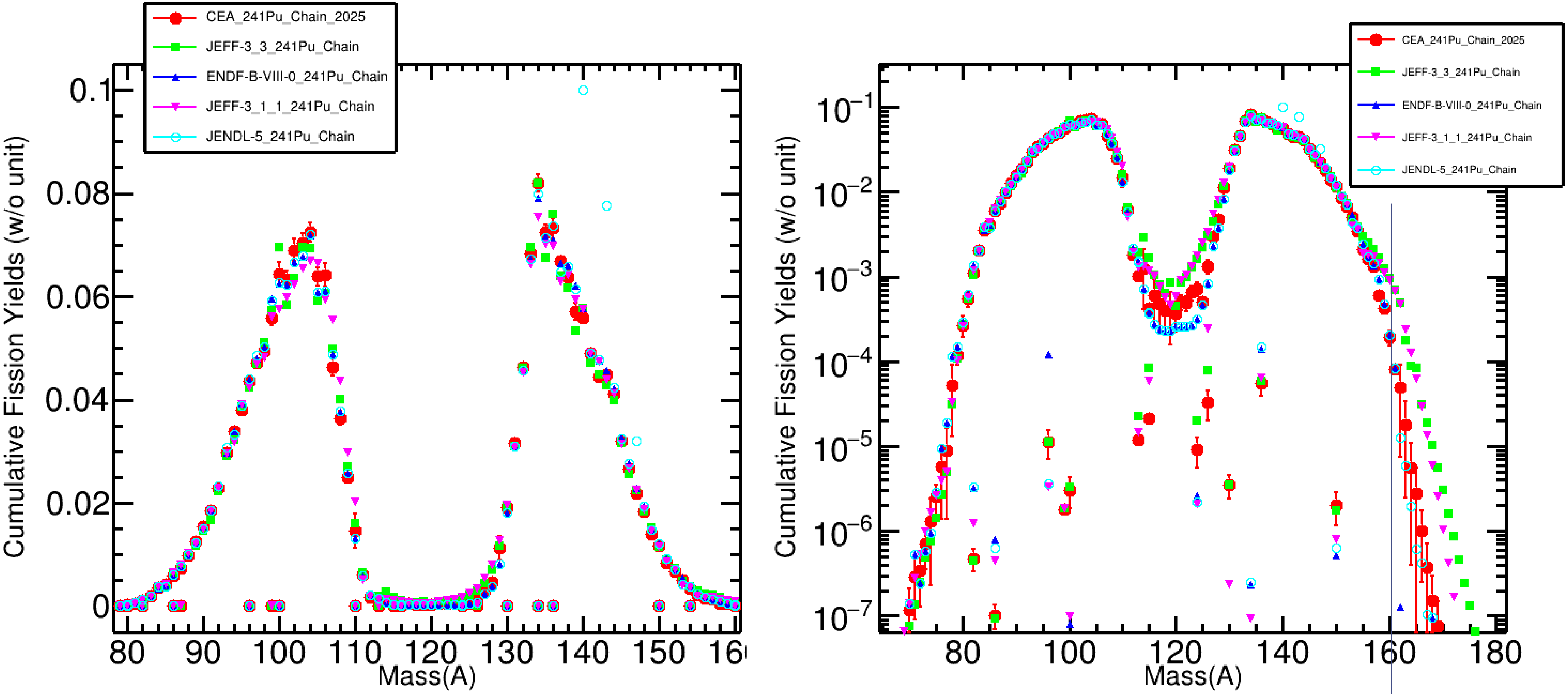
?



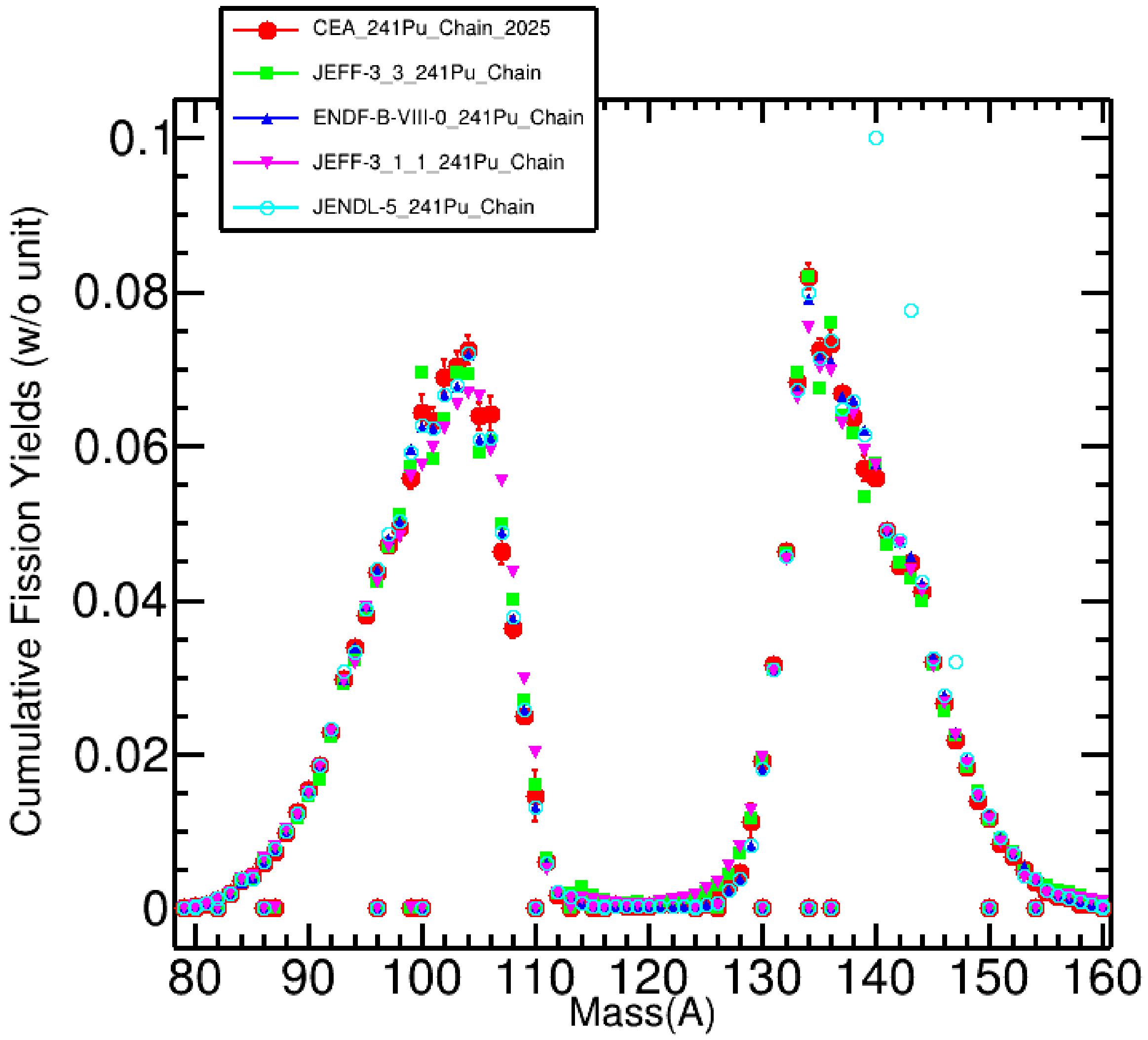
$^{233}U(n,f) \rightarrow$ 136* & 142*
$^{235}U(n,f) \rightarrow$ 134* & 138* & 144*
$^{239}Pu(n,f) \rightarrow$ 134* & 136* & 138*
$^{241}Pu(n,f) \rightarrow$ 134* & 136*

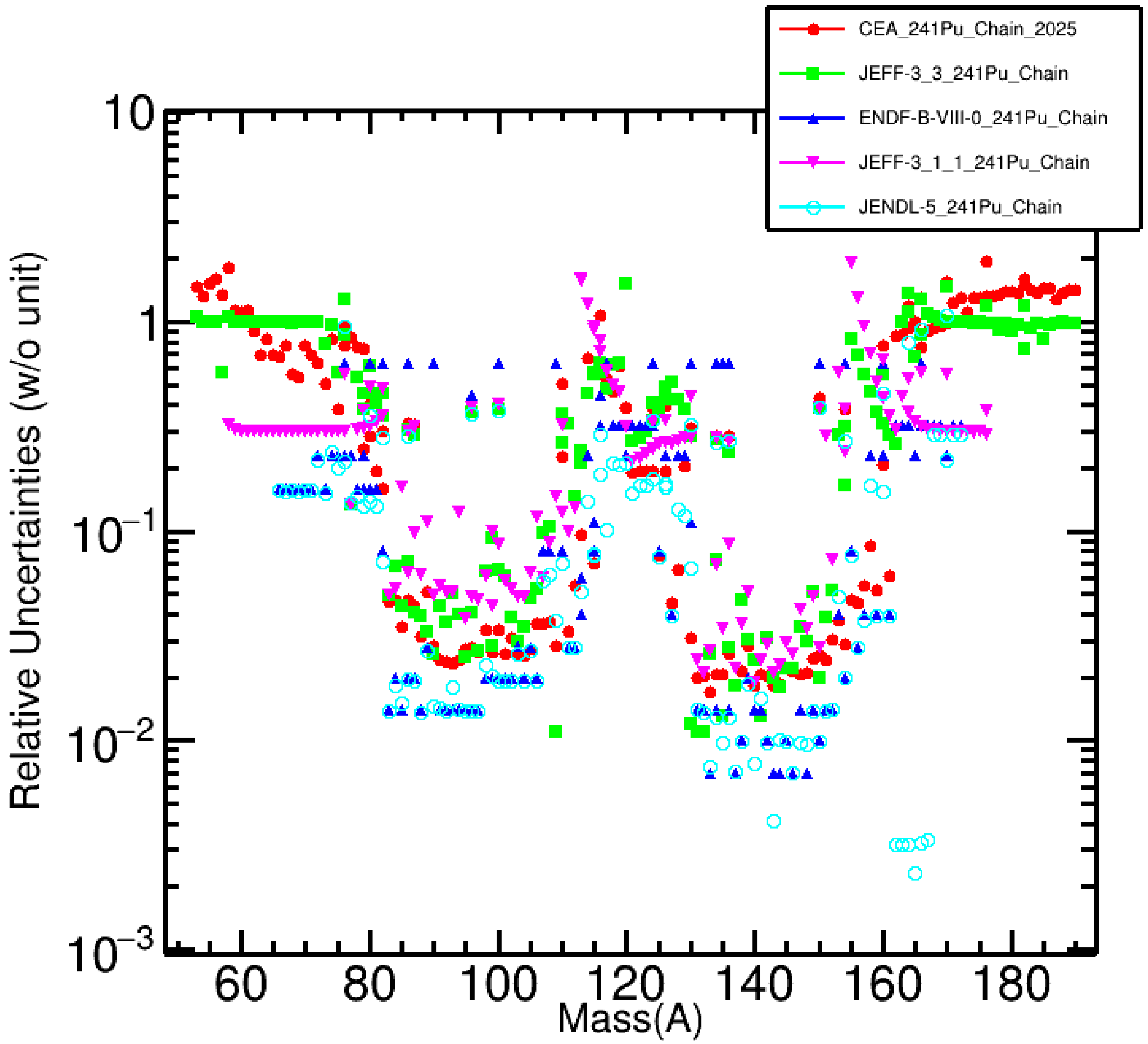
S.-M. Cheikh, G. Kessedjian et al., Eur. Phys. J. A, 60 11 (2024) 222
C. Simenel, A.S. Umar, Formation and dynamics of fission fragments. Phys. Rev. C 89(3), 031601 (2014)
G. Scamps, C. Simenel, Impact of pear-shaped fission fragments on mass-asymmetric fission in actinides. Nature 564(7736), 382–385 (2018)

$^{241}Pu(n_{th},f)$ Chain Yields 2025

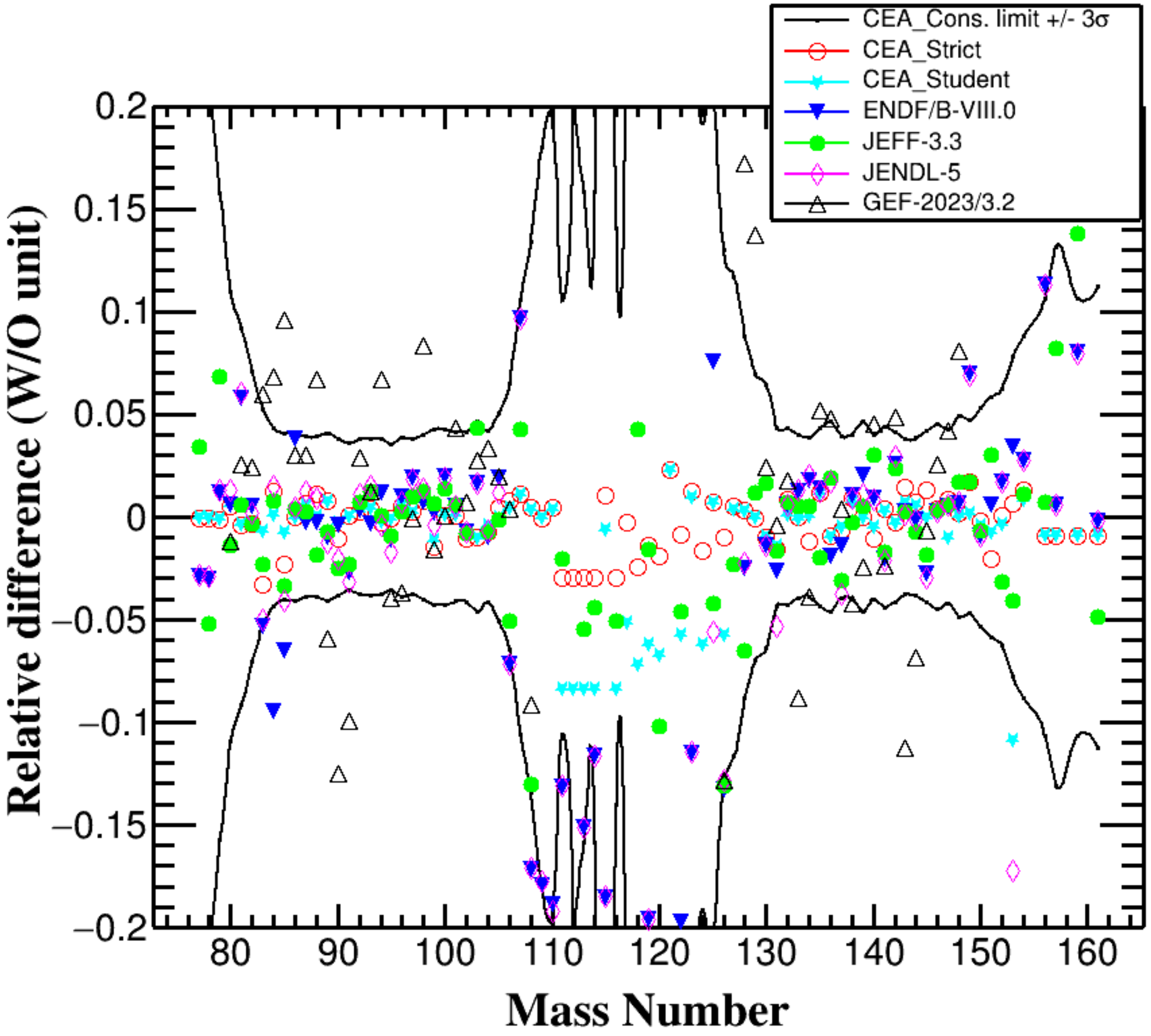


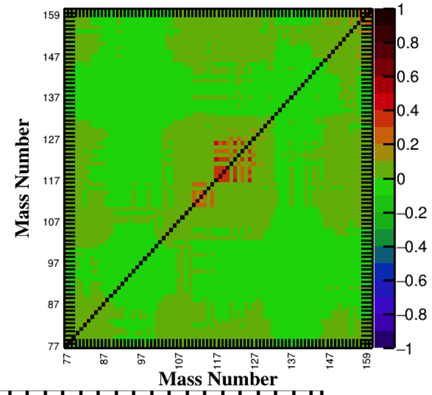
$^{241}Pu(n_{th},f)$ Chain Yields 2025

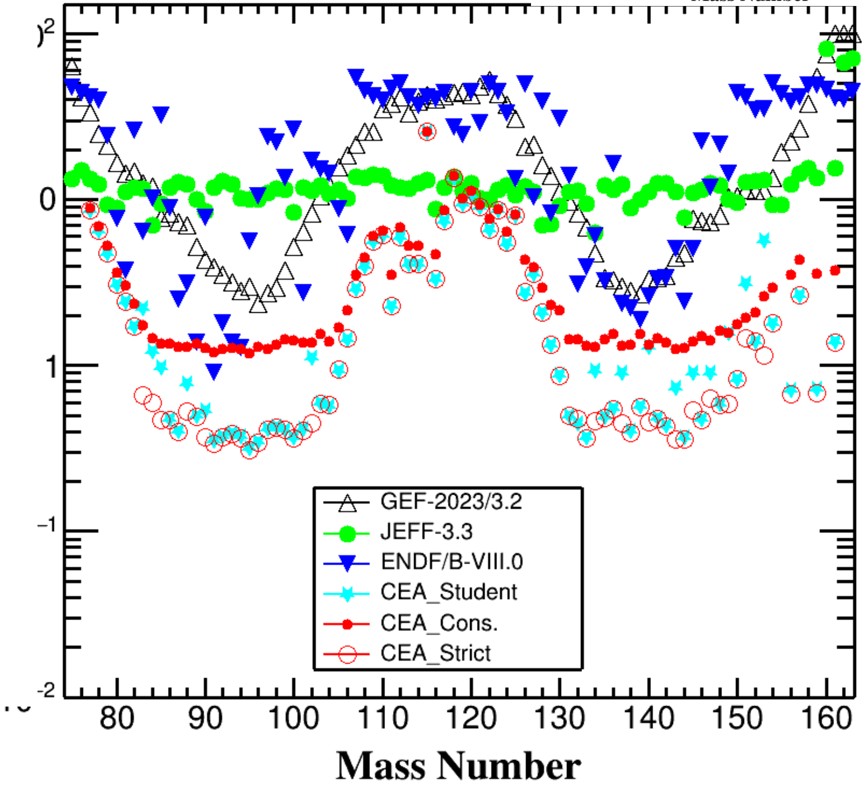




$^{235}U(n_{th},f)$: Exclusion plot in reference to JEFF-4T4 evaluation

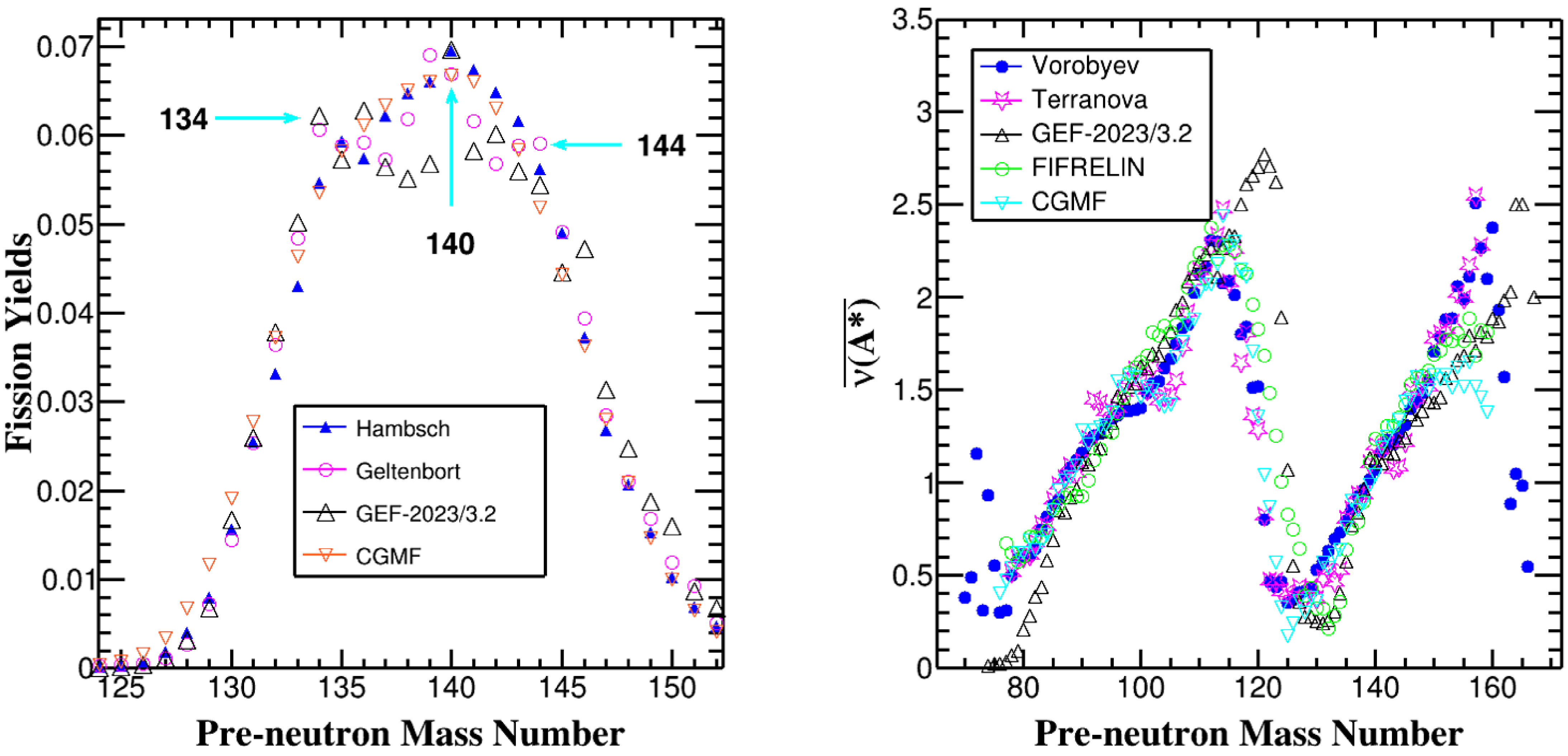




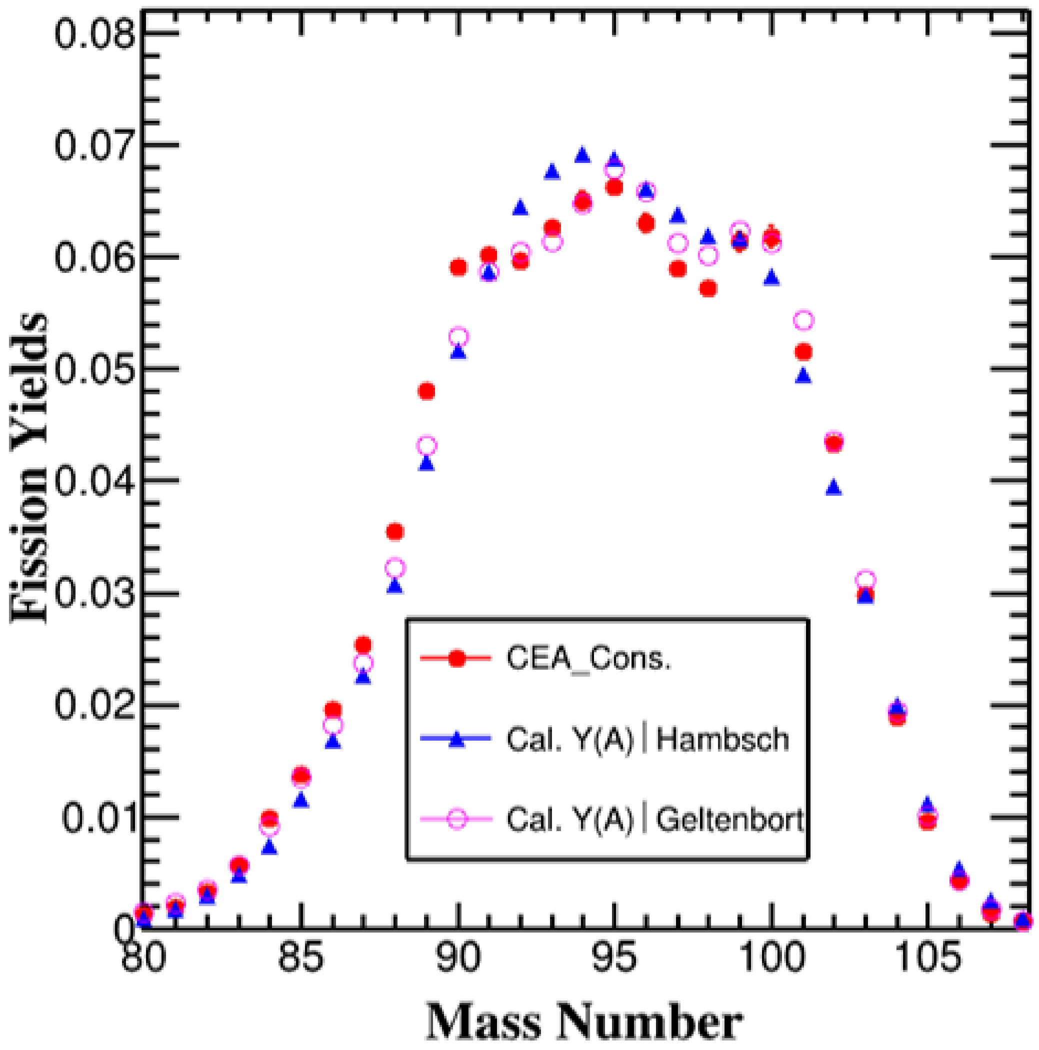


^{235}U(n_{th},f): From pre-n yields to post-n yields

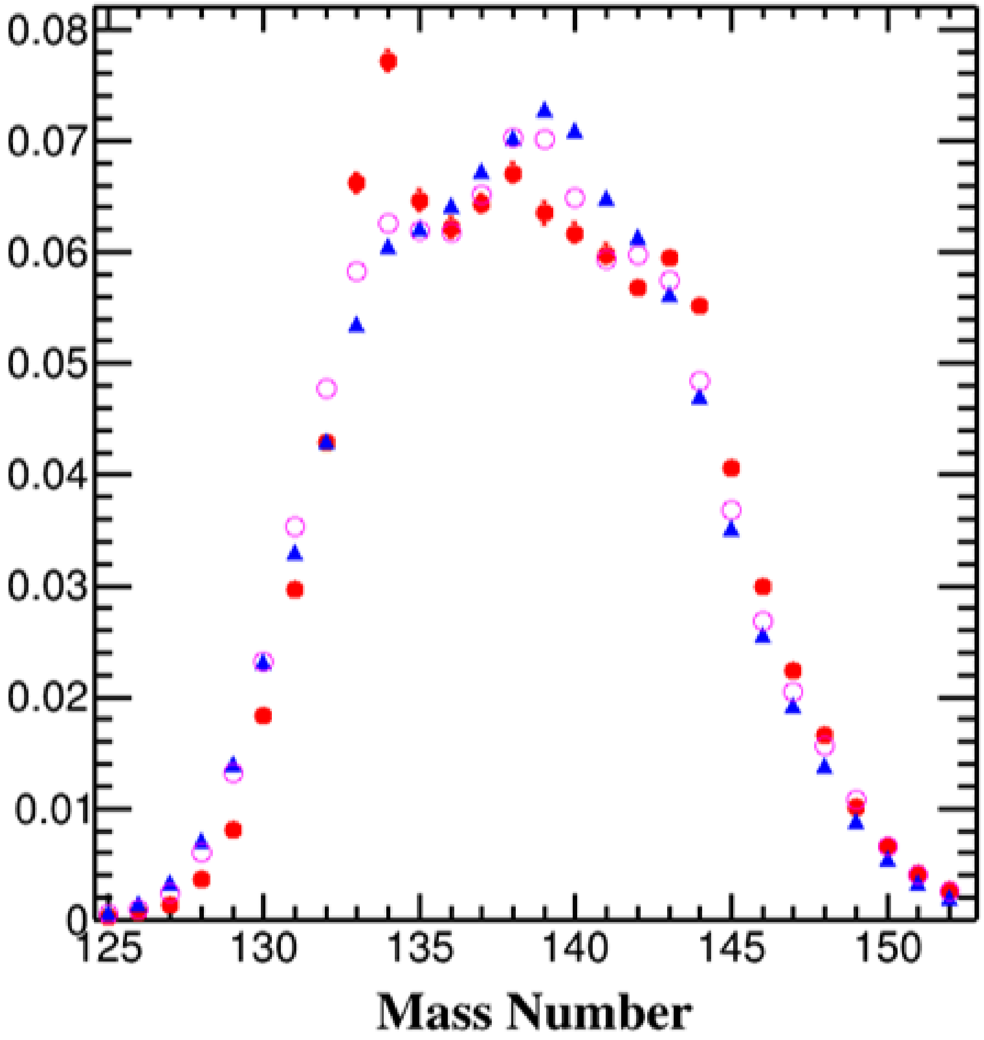
$^{235}U(n_{th},f)$: From Pre-neutron yields to post-neutron yields



$^{235}U(n_{th},f)$: From Pre-neutron yields to post-neutron yields → Sensitivity to Y(A*)

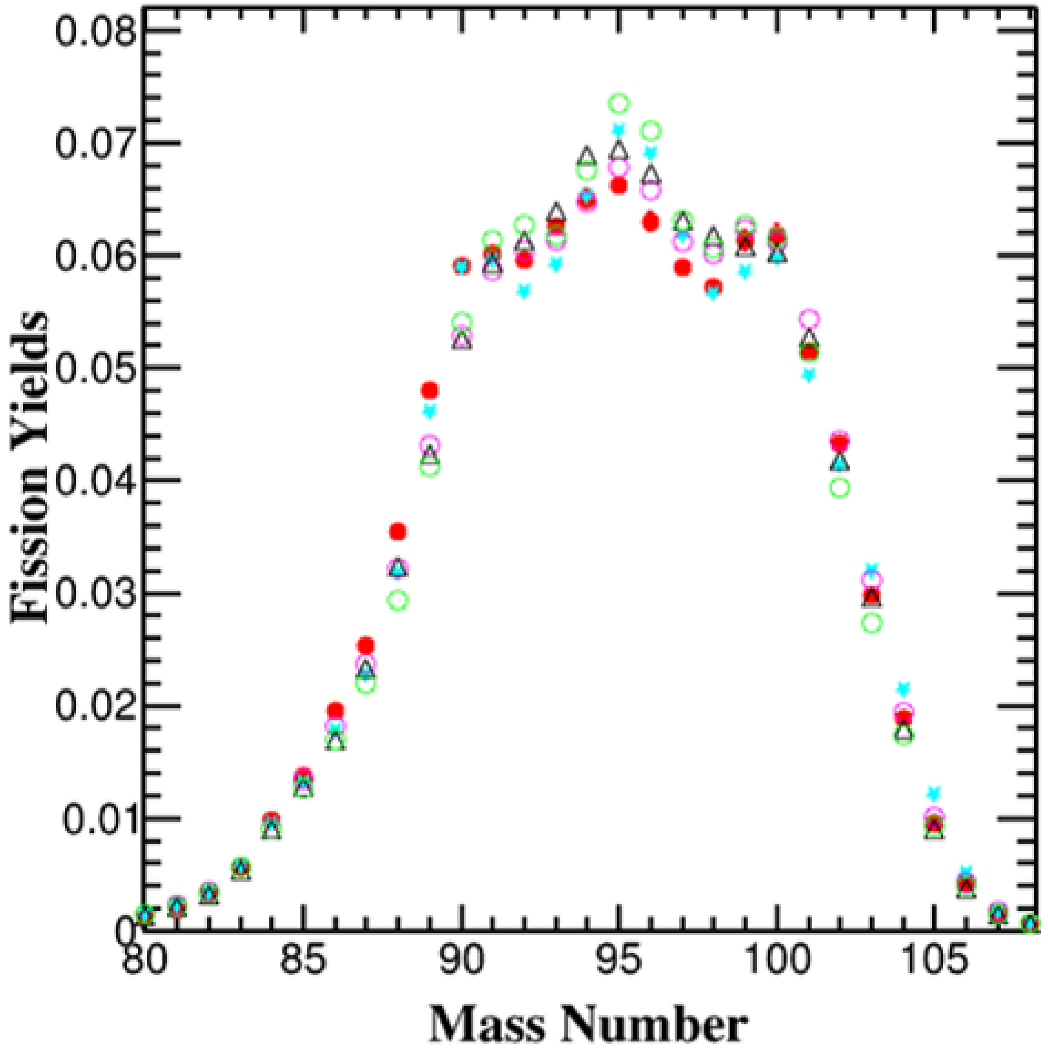


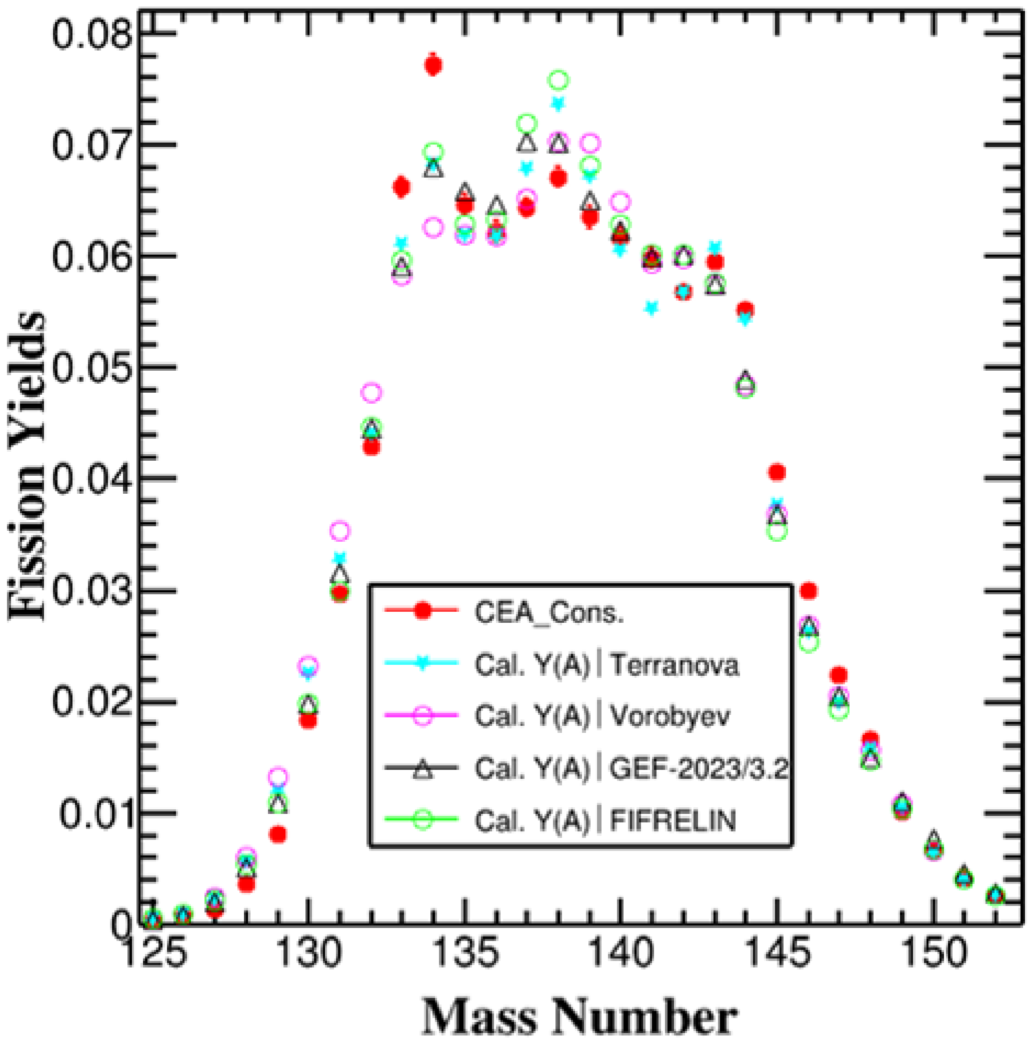
$$Y_A = \sum_{\nu} Y_{A^*} \cdot P(\nu \mid A^*) \text{ with } A^* = A + \nu$$



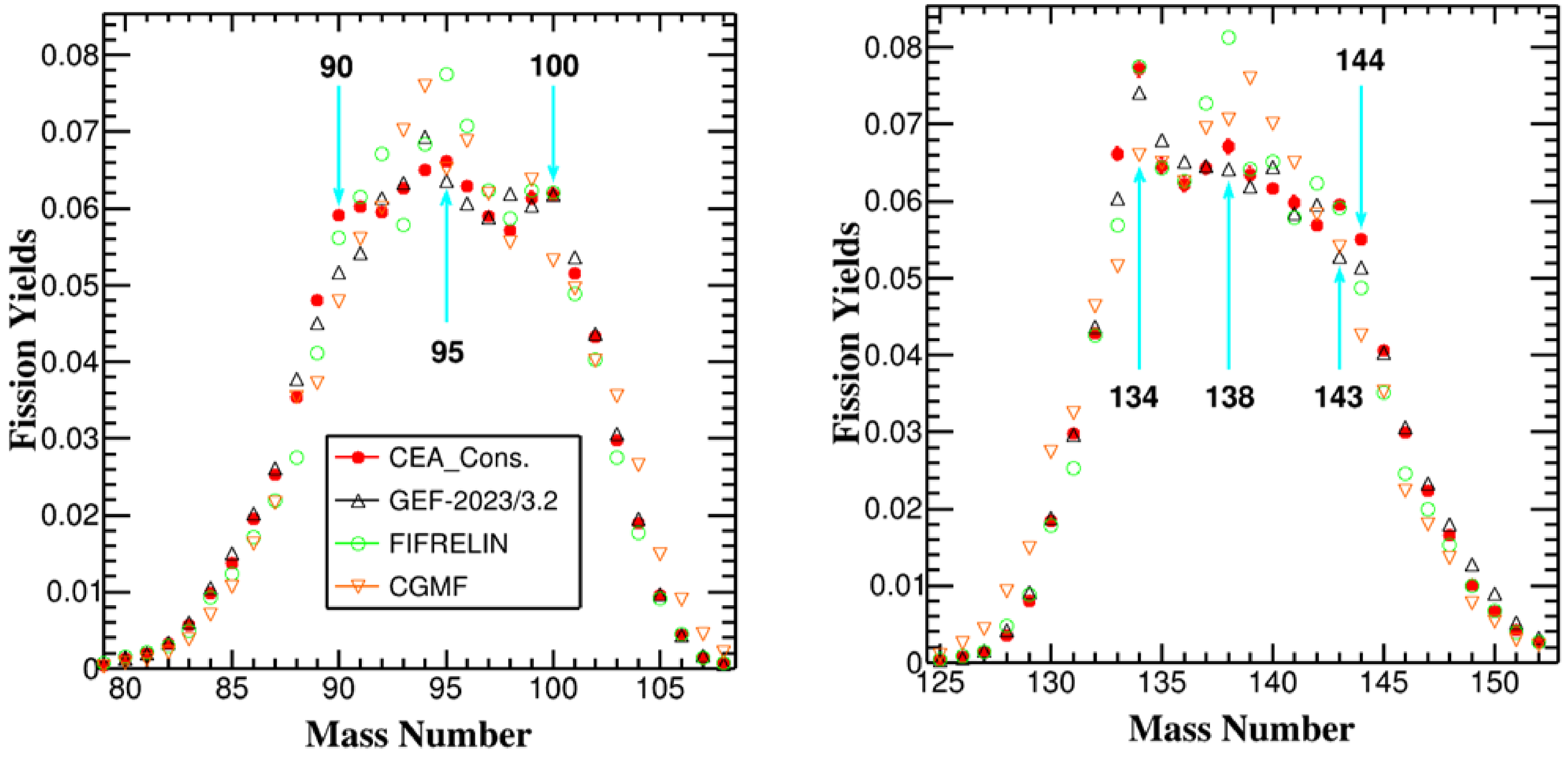
Impact of pre-neutron mass yields on post-neutron mass yields using the Vorobiev's saw-tooth data

$^{235}U(n_{th},f)$: From Pre-neutron yields to post-neutron yields → Sensitivity to $\nu(A^*)$

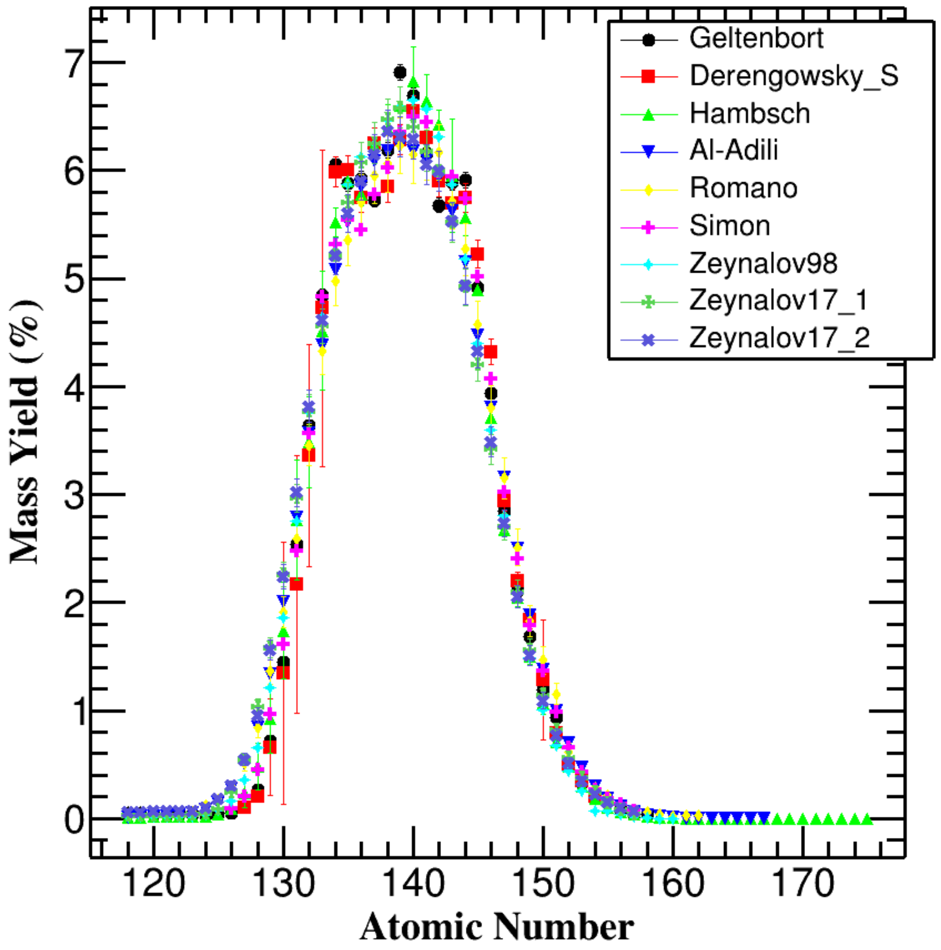


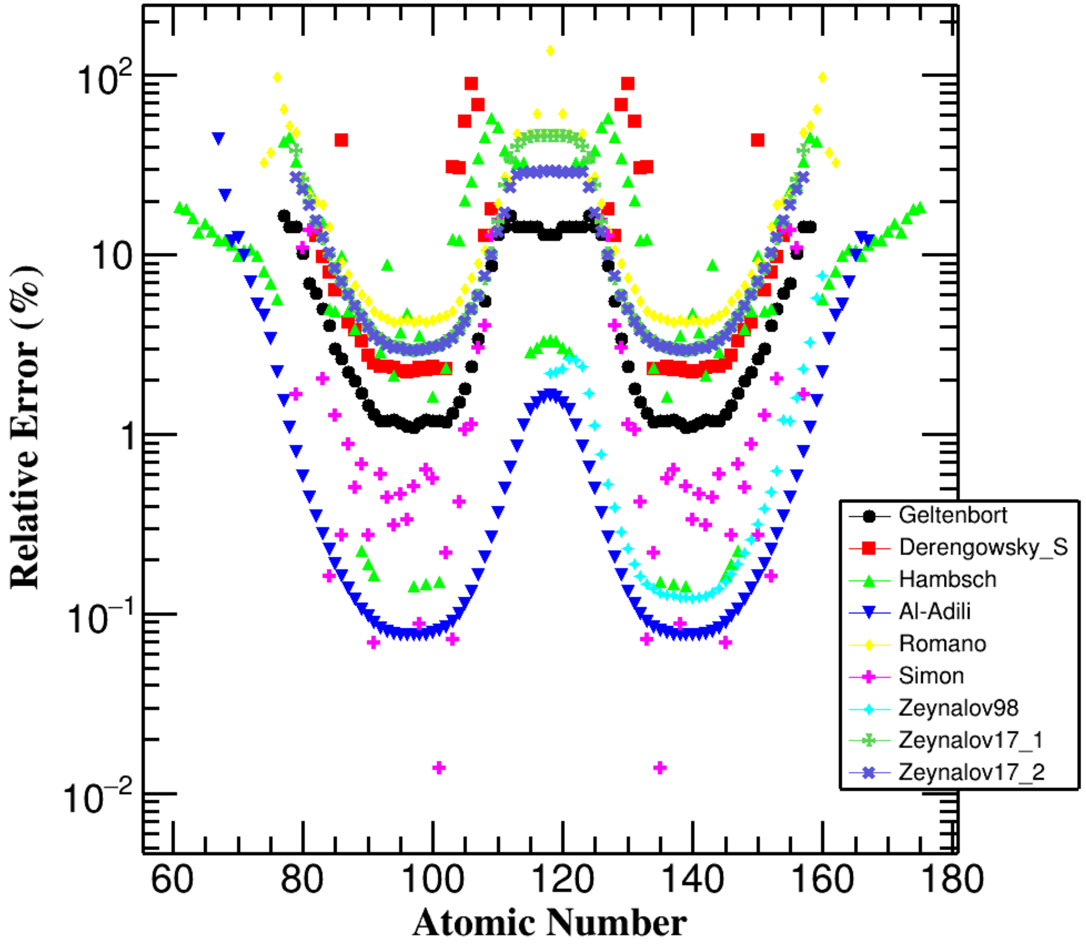


$^{235}U(n_{th},f)$: From Pre-neutron yields to post-neutron yields → comparison to codes

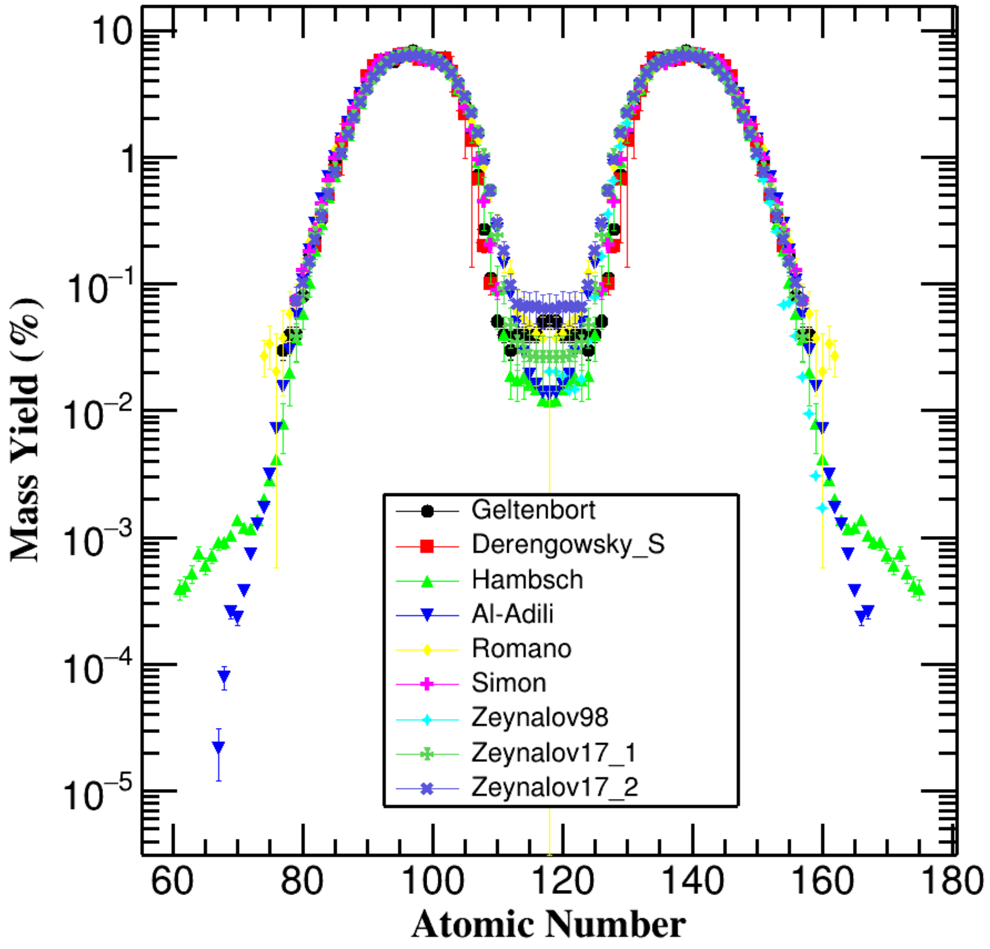


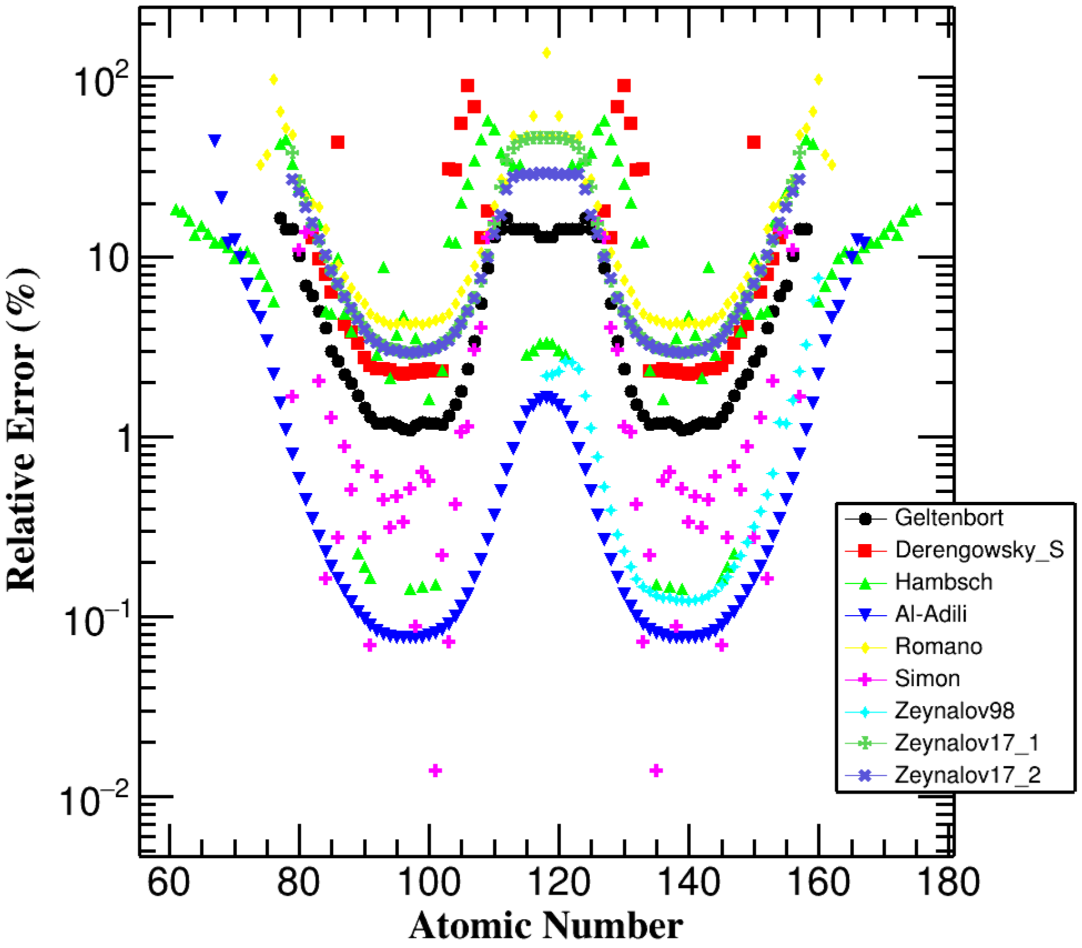
Perspectives : pre-n mass yield analysis





Perspectives : pre-n mass yield analysis

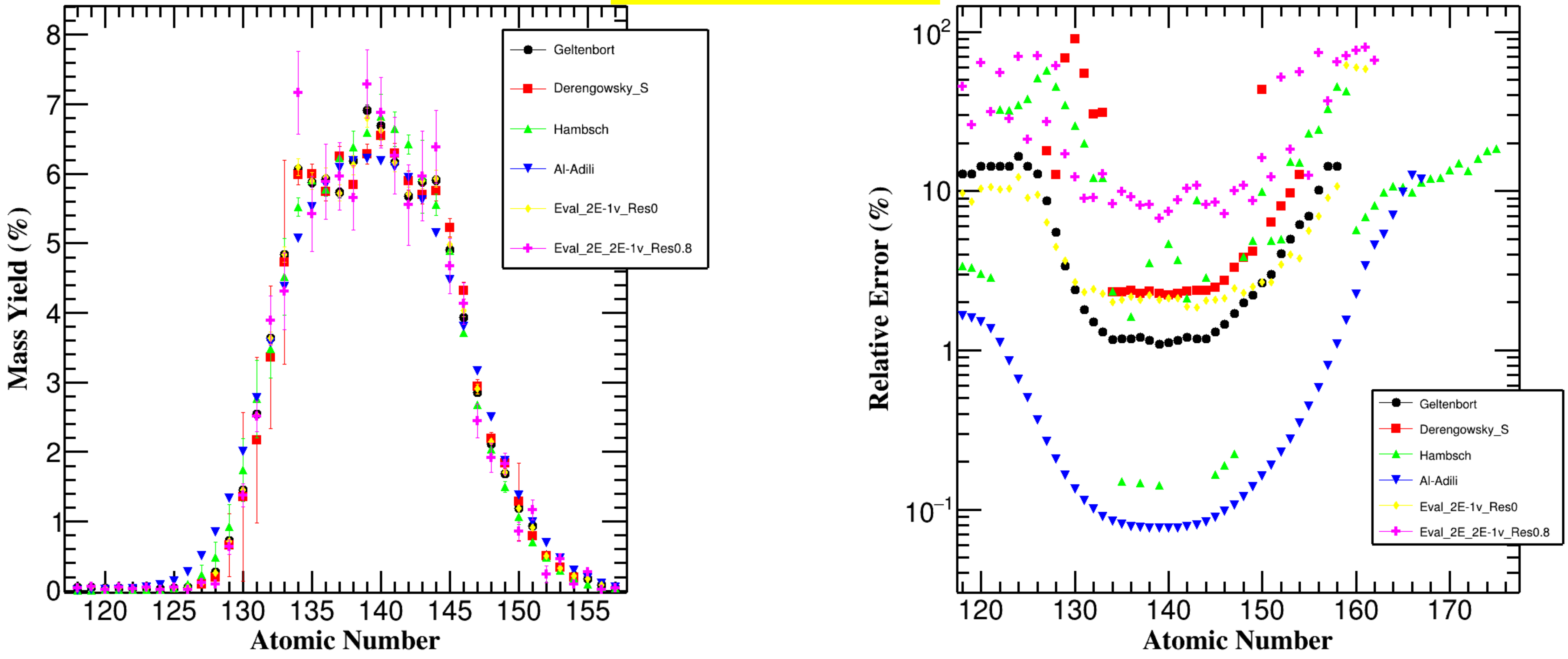




A. Regonesi PhD Thesis (2024-2027)

Perspectives : pre-n mass yield analysis → MCMC method

Preliminary Results



Geltenbort's data : Exp. Resolution Res(A)~0.8 uma

A. Regonesi PhD Thesis (2024-2027)

Back-up